CH101 Design Guide

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1 INTRODUCTION

1.1 ABSTRACT

This CH101 Design Guide shows how to design-in Ultrasonic Sensors of the CH101 family. This guide explains the Ultrasonic operation of CH101 Short Range Ultrasonic Sensor, hardware selection, integration guidelines, performance tuning and calibration with our software and testing. This document is intended to help one attain a general understanding of how the CH101 product works and goes over the design process to design and tune the device for usage.

1.2 INTRODUCTION

A CH101 sensor is an ultrasonic transceiver, meaning that it can both transmit and receive ultrasound signals. Unlike various types of passive sensors which simply measure their surrounding conditions, the CH101 actively injects a signal into its environment. To perform a basic distance measurement, the sensor will emit a very brief pulse of ultrasound. It then immediately enters a “listening” state, in which it samples the received sound, attempting to identify an echo of the pulse that has been reflected off an object in the sensor’s vicinity. If an ultrasound pulse is identified, the sensor will analyze the signal to determine the timing and then report the ToF of the received pulse. The actual distance travelled by the ultrasound can then be calculated from the ToF based on the speed of sound.

This design Guide focuses on CH101 usage applications and will help you understand:

- Ultrasonic Technology of the CH101
- Recommended HW module selection process
- Module HW mounting guidelines
- Performance tuning of CH101 using TDK/Chirp available SW

Table 1-1. Acronyms and Abbreviations

Acronyms and Abbreviations	Definition
ASIC	Application-specific integrated circuit
FoV	Field-of-View
FPC	Flexible printed circuit
FWHM	Full-width half-maximum
IC	Integrated circuit
IR	Infrared
LSB	Least significant bits (ADC counts)
MEMS	Micro-electro-mechanical systems
PSA	Pressure-sensitive adhesive
PCB	Printed circuit board
PCBA	Printed circuit board assembly
PIF	Particle ingress filter
PMUT	Piezoelectric micromachined ultrasonic transducer
ToF	Time-of-Flight

1.3 CH101 FEATURES

- Fast, accurate range-finding
    - Operating range from 4 cm to 1.2m
    - Sample rate up to 100 samples/sec
    - mm RMS range noise at 30 cm range
    - Programmable modes optimized for medium and short-range sensing applications
    - Customizable field-of-view (FoV) up to 180° with different acoustic housings
    - Multi-object detection
    - Works in any lighting condition, including full sunlight to complete darkness
    - Insensitive to object color, detects optically transparent surfaces (glass, clear plastics, etc.)
- Easy to integrate
    - Single sensor for receive and transmit
    - Single 1.8V supply
    - I2C Fast-Mode compatible interface, data rates up to 400 kbps
    - Dedicated programmable range interrupt pin
    - Platform-independent software driver enables turnkey range-finding
- Miniature integrated module
    - 3.5 mmx 3.5 mm x 1.26 mm, 8-pin LGA package
    - Compatible with standard SMD reflow
    - Low-power SoC running advanced ultrasound firmware
    - Operating temperature range: -40°C to 85°C
- Ultra-low supply current
    - 1 sample/s:
        - 13 µA (10 cm max range)
        - 15 µA (1.0 m max range)
    - 30 samples/s:
        - 20 µA (10 cm max range)
        - 50 µA (1.0 m max range)

1.4 CH101 DESIGN FLOW

The following is typical Product Design Flow for the CH101 for established Product Platforms:

Figure 1-1. Product Design Flow

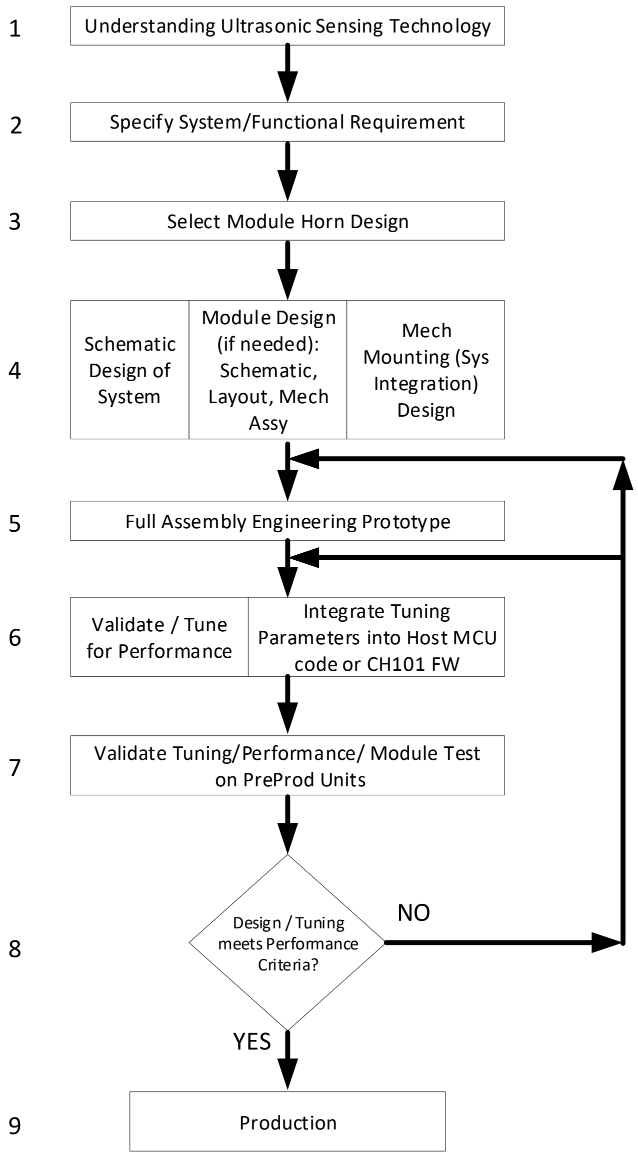


Table 1-2. Design Flow Supporting Documentation

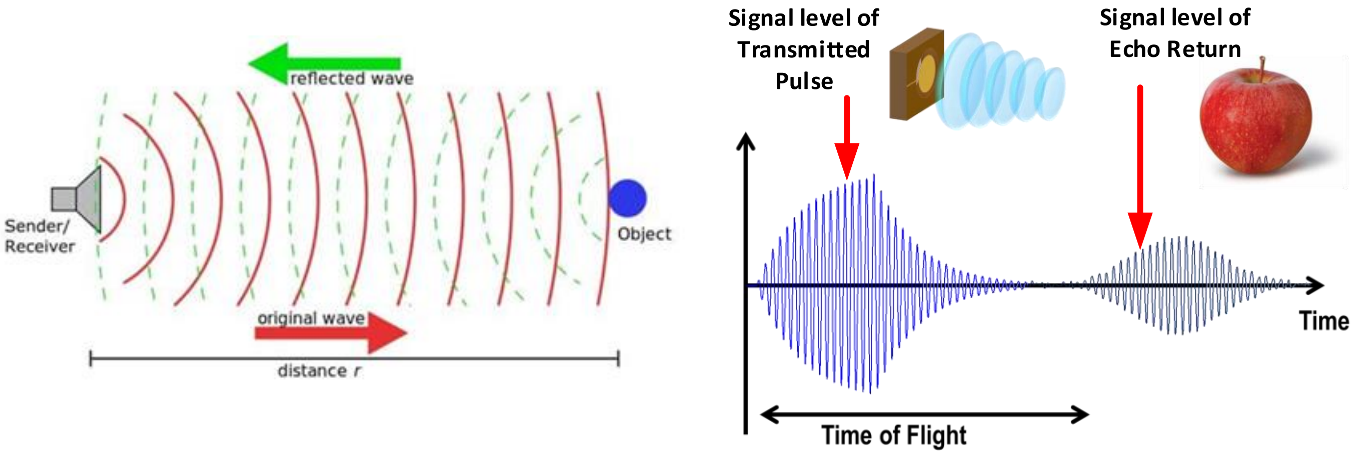
Steps in Design Flow	TDK Chirp Reference Document	
	Document Number: Name	**Section**
1) Understanding Ultrasound Technology	PB-000110: DK-CH101 Product Brief	
2) Specify Requirements		
3) Select Horn	PB-000082: AH-10100-180180 Acoustic Housing Brief	
4) System Design	DS-000331: CH101 Datasheet AN-000158: CH101 Mechanical Integration Guide	2 3
5) Engineering Prototype	N/A	
6) Tune, Validate, and Integrate Parameters	AN-000180: CH101 & CH201 Smart Sonic Eval Kit AN-000155: SonicLink Software Quick Start Guide AN-000154: SmartSonic Hello Chirp Application Hands-on Exercise AN-000175: SonicLib Programmers Guide AN-000240: Application User Guide for Floor Type Detection of Robotic Vacuums AN-000349: Application User Guide for Floor Type Detection and Cliff Detection for Robotic Vacuums	 5 6
7) Validate tuning and Module Test on PreProd Units	AN-000169: Ultrasonic Module Pulse Echo Test Procedure	4
8) Validated Design?	N/A	
9) Production	AN-000159: CH101 and CH201 Ultrasonic Transceiver Handling and Assembly Guidelines AN-000223: Acoustic Interface Gluing Procedure for Chirp Ultrasonic Sensing Modules	

2 HOW A CH101 WORKS

2.1 BASICS OF ULTRASONIC SENSING

Ultrasonic Sensors generate sound pressure waves in the ultrasonic range (above 18 kHz) and senses the reflected echo. By interpreting the reflected energy (an echo), targets can be identified, and a range can be calculated. Ultrasonic Sensors do not require any physical contact but do need an air medium. Objects and ranges that can be detected in an air medium ranges from 3 cm to a few meters.

Figure 2-1. Ultrasonic sensing basics



2.2 MEASURING DISTANCE USING TIME OF FLIGHT

Most of us have had the experience of seeing a lightning bolt and then using the delay between the flash and the arrival of the thunder to estimate how far away the lightning strike was. For many, the initial flash triggers an immediate response of counting the seconds until the thunder is heard. If we happen to know a rough estimate of the speed of sound (e.g. 3 seconds per kilometer, or 5 seconds per mile), we can easily convert the observed time into a useful approximate distance.

The CH101 ultrasonic sensors use this same approach, measuring the time it takes for sound to arrive after a known event (A Pulsed sound wave) to determine distances at much closer ranges and with high accuracy. This elapsed time is known as the “Time of Flight” (ToF). Half of elapsed time is the time it takes a pulsed sound wave to hit and reflect off the object. Since Speed of Sound is a Constant (C), Range (R) can be calculated when ToF is measured.

$$Range\ (R) = C\ x \frac{ToF}{2}$$

- Example calculation (at sea level air pressure):

  Speed of Sound of air (C) = 343 m/s

  ToF measured = 3 ms

  Range = <u>0.514 meters</u>

2.3 WHY AND WHEN TO USE ULTRASONIC SENSING

Ultrasonic Sensors are ideal when you need to detect or get range data from a specific range. Ultrasound sensors can detect a variety of material and surfaces, objects made of metal, glass, wood, water, humans, and low sound absorbing material can be detected. For known reflected distance applications, the measured response of energy can differentiate a change in materials.

When compared to Infrared (IR) ToF Sensors:

- Ultrasonic ToF is much lower power than IR ToF
  - Typical competing IR ToF: 20 mW at 10 samples/sec,
  - Chirp's CH101: 50 µA at 10 samples/sec (~500x lower power)
- IR ToF sensors are sensitive to lighting
  - Range and accuracy are greatly reduced by ambient light
  - Does not work at all in sunlight
- Ultrasonic ToF provides much lower-noise range sensing
  - Typical IR ToF spec for a white target indoors is 4.8 cm RMS range noise at 120cm range
  - Chirp's CH101 has 10x lower noise at 120 cm (5 mm RMS)
  - Chirp's CH201 has 100x lower noise at 120 cm (0.5 mm RMS)
- IR ToF sensors have a very narrow field-of-view (FoV)
  - Typical IR ToF: 25 degrees
  - Chirp: ~180 degrees, can be custom tailored to a narrower FoV if desired
- IR ToF can operate beneath cover glass, but
  - Cover-glass reflects IR light, creating cross-talk
  - With high cross-talk, IR ToF sensor's maximum range is greatly reduced

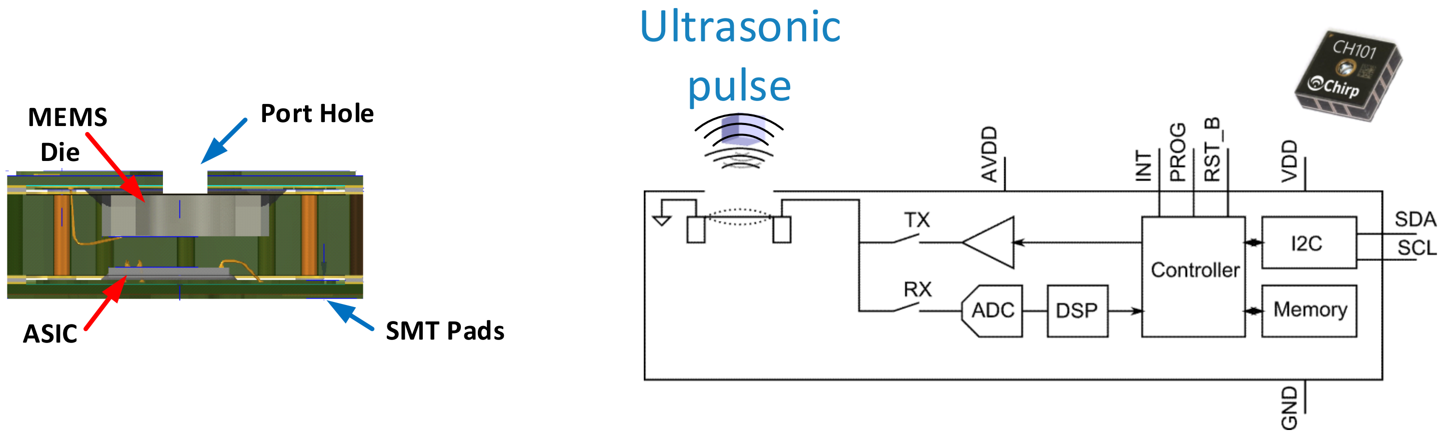
2.4 CH101 SENSOR

A CH101 sensor is an ultrasonic transceiver, meaning that it can both transmit and receive ultrasound signals. Unlike various types of passive sensors which simply measure their surrounding conditions, the CH101 actively injects a signal into its environment. To perform a basic distance measurement, the sensor will emit a very brief pulse of ultrasound. It then immediately enters a “listening” state, in which it samples the received sound, attempting to identify an echo of the pulse that has been reflected off an object in the sensor’s vicinity. If an ultrasound pulse is identified, the sensor will analyze the signal to determine the timing and then report the ToF of the received pulse. The actual distance travelled by the ultrasound can then be calculated from the ToF based on the speed of sound.

The CH101 sensor contains a piezoelectric micro-machined ultrasonic transducer (PMUT) as part of the MEMS (micro-electro-mechanical systems)

Please refer to DS-000331 CH101 Datasheet for more detailed information

Figure 2-2. Sensor Profile & Chirp CH101 Block Diagram



2.4.1 Use of Level Shifters

To achieve compatibility between ICs with different voltage requirements, level shifters or logic level shifters are required to translate signal from one voltage domain to another, or in other words one logic level to another. In this case it is used to shift voltage level between CH101 to MCU and MCU to CH101. Choosing the right level shifter heavily relies on the factor of its alignment with each of the I/O pin on the CH101 chip. The table below elaborates on each CH101 I/O pin type:

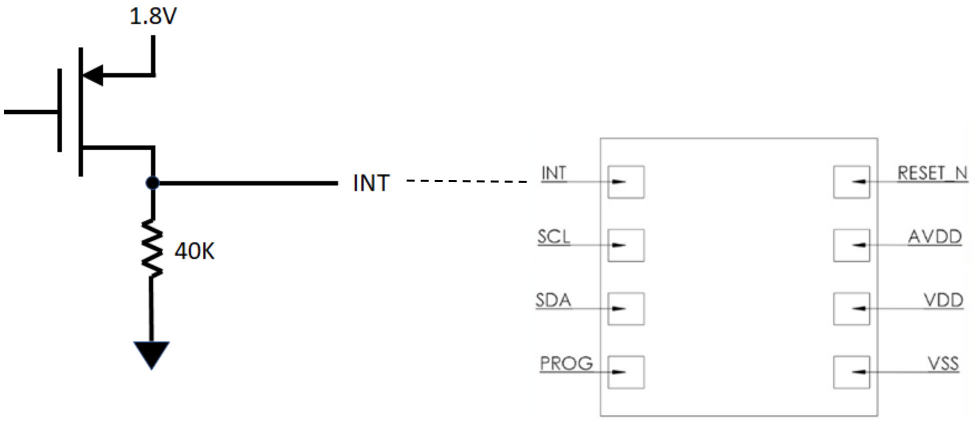
Table 2-1. CH101 I/O Types

PIN	I/O NAME	I/O TYPE
1	INT	High-side open drain
2	SCL	Open drain
3	SDA	Open drain
4	PROG	Digital input
8	RESET_N	Digital input

SDA and SCL are open drain. PROG and RESET_N are digital inputs without any pullup/pulldown resistors. SDA, SCL, PROG and RESET_N can be used with typical I2C level shifters without any issues. The PROG line, which is active high, can be level shifted with a voltage divider without any impact on current consumption during normal operation (when PROG is normally low), or it can use a I2C level shifter.

INT operates as a bi-directional I/O with a high-side common drain output, with an internal pull-down resistor as shown in Figure 2-3. INT is a unique circuit and has certain limitations due to the 40kΩ pull down resistor. Unfortunately, I^2C compliant level shifters do not work with this pin because of the internal pull-up resistors in those types of level shifters. Special handling of the INT line while using a level shifter is required to ensure proper resetting of this line.

Figure 2-3. INT Line I/O Circuit Stage

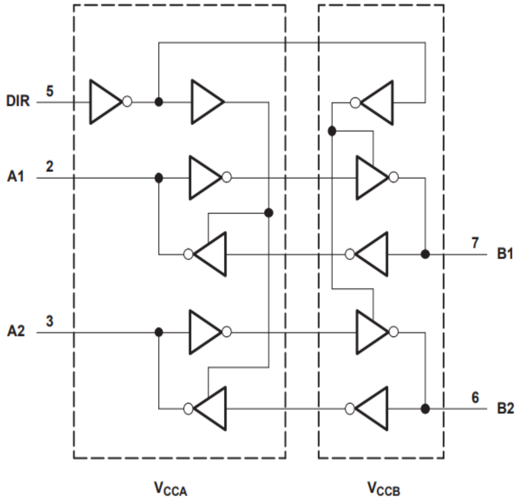


INT is used bidirectionally in CH101. INT is used as an input when the Soniclib driver is a) calibrating the CH101 RTC, or b) triggering CH101 to take a measurement (Hardware Trigger mode). INT is used as an output when the CH101 wishes the MCU to know that a measurement is finished, and data should be read out.

The high-side common drain output of INT is intended to be used as follows: when either the sensor or the host MCU wants to set the line high, they drive the line high actively for a brief (typically 1-10us) period. Then, the 40kΩ pull down resistor is allowed to reset the INT line to a low level. As a direct result, any usage of a pull-up resistor on the INT line would be incorrect, as it would allow static current to flow from the pull-up resistor to the internal pull-down resistor and prevent the logic level of INT from reaching 0V.

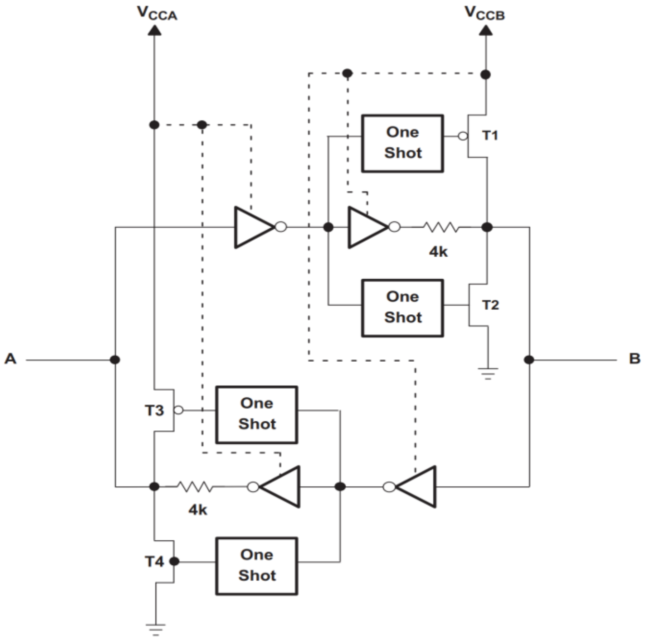
There are several options to level shift the INT line. For an MCU which is not pin limited, a good choice is the TI SN74LVC2T45 because it offers manual directional control line, allowing the Soniclib driver to specifically set the direction of the INT line. This dual supply bus transceiver is designed for asynchronous communication between two data buses and can be configured to accept and supply any voltage from 1.65V to 5.5V, allowing bidirectional translation of voltage nodes between any of 1.8V, 2.5V, 3.3V and 5V. The direction control pin (DIR) can be controlled allowing the system to set the appropriate signal direction, see Figure 2-4. The SN74LVC2T45 dual rail design can be configured to let each of the port operate independently over the power supply range of 1.65V - 5.5V, hence we can precisely level shift voltage between CH101 → MCU & MCU → CH101 by bidirectionally restraining the signal to 1.8V and/or to 3.3V.

Figure 2-4. SN74LVC2T45 Function Block Diagram



Another level shifter, TXB0104QPWRQ1 can be used but it requires certain code to run in the SonicLib driver. Refer to Figure 2-5. Because of the 4kΩ resistor in series with the push-pull output driver, after the MCU sets INT high (i.e. triggers CH101), the CH101 cannot set the INT low by itself, since the INT`s 40kΩ resistor cannot overcome the TXB0104’s 4kΩ internal resistor, resulting in the pull up being stronger than the pull down.

Figure 2-5. Architecture of TXB0104 I/O Cell



This issue can be handled by clearing the INT line using the MCU:

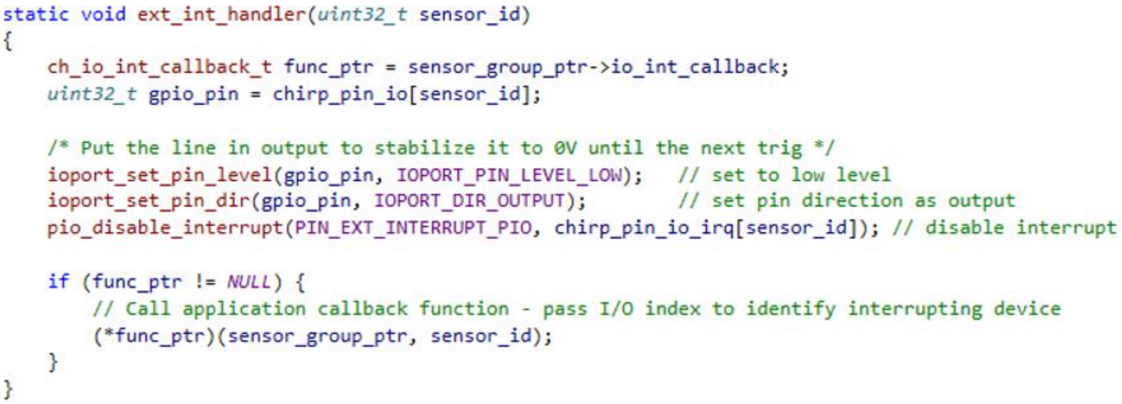
a. [CH101 → MCU direction] CH101 sets INT_1v8 high and TXB translates this to INT_3v3. The MCU, upon receiving an interrupt from the INT line, will then immediately drive the INT_3v3 line low for a short time. This will cause the TXB0104 to set INT_1v8 low. CH101 can then hold INT_1v8 low with the 40kΩ resistor until the next event. MCU tri-states the INT_3v3 until the next event.

b. [MCU → CH101 direction] MCU sets INT_3v3 high for a short time and then drives it low again. TXB0104 translates the pulse. Thereafter, CH101 can then hold INT_1v8 low with the 40kΩ resistor until the next event. MCU tri-states the INT_3v3 until the next event.

Below is the source code used to work around the TXB0104`s internal resistors, include the following functions from provided sample code base:

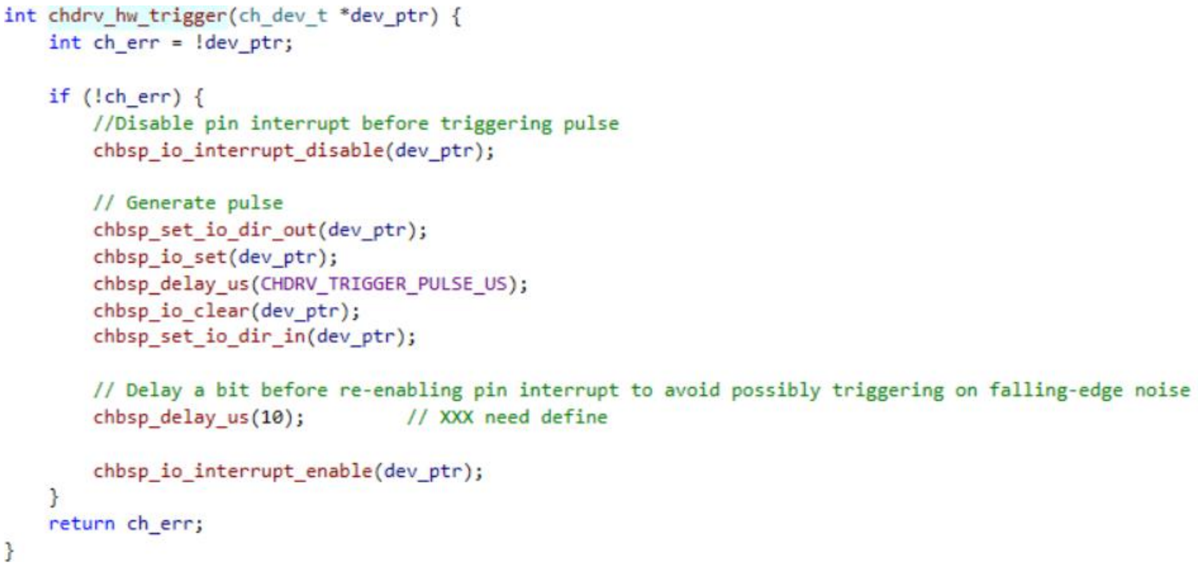
Figure 2-6. Sample Code when using TXB0104

For a. [CH101 → MCU direction], please reference *static void ext_int_handler(uint32_t sensor_id)* function in *source\board\HAL\src\bsp_misc_samg55.c*. Below is the code snippet:



```
static void ext_int_handler(uint32_t sensor_id)
{
    ch_io_int_callback_t func_ptr = sensor_group_ptr->io_int_callback;
    uint32_t gpio_pin = chirp_pin_io[sensor_id];

    /* Put the line in output to stabilize it to 0V until the next trig */
    ioport_set_pin_level(gpio_pin, IOPORT_PIN_LEVEL_LOW);   // set to low level
    ioport_set_pin_dir(gpio_pin, IOPORT_DIR_OUTPUT);        // set pin direction as output
    pio_disable_interrupt(PIN_EXT_INTERRUPT_PIO, chirp_pin_io_irq[sensor_id]); // disable interrupt

    if (func_ptr != NULL) {
        // Call application callback function - pass I/O index to identify interrupting device
        (*func_ptr)(sensor_group_ptr, sensor_id);
    }
}
```

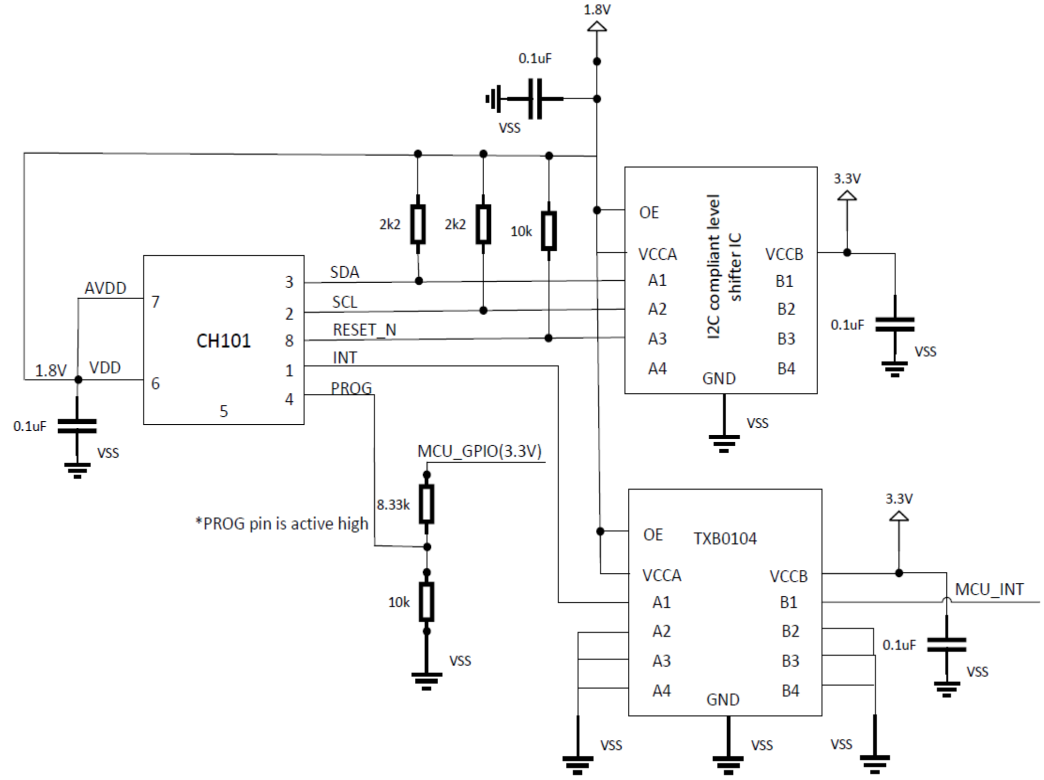
For b. [MCU → CH101 direction], please reference int chdrv_hw_trigger(ch_dev_t *dev_ptr) function in source\drivers\chirpmicro\src\ch_driver.c



```
int chdrv_hw_trigger(ch_dev_t *dev_ptr) {
    int ch_err = !dev_ptr;

    if (!ch_err) {
        //Disable pin interrupt before triggering pulse
        chbsp_io_interrupt_disable(dev_ptr);

        // Generate pulse
        chbsp_set_io_dir_out(dev_ptr);
        chbsp_io_set(dev_ptr);
        chbsp_delay_us(CHDRV_TRIGGER_PULSE_US);
        chbsp_io_clear(dev_ptr);
        chbsp_set_io_dir_in(dev_ptr);

        // Delay a bit before re-enabling pin interrupt to avoid possibly triggering on falling-edge noise
        chbsp_delay_us(10);          // XXX need define

        chbsp_io_interrupt_enable(dev_ptr);
    }
    return ch_err;
}
```

FXL2TD245 is another level shifter that can be used as alternative of the TXB0104. Figure 2-7 represents the system schematic scenario to convert all the CH101`s I/Os to 1.8V with the use of level shifters.

Figure 2-7. System Schematic Scenario



2.4.2 Operating Modes of CH101

- Free-Running (Self-Timed) Transmit/Receive Mode
    - Runs autonomously at a user specified sample rate
    - INT pin is configured as an output
    - Pulses the INT pin high when a new range sample is available.
    - When the sensor is in Free-Running mode, it uses a periodic timer based on the sensor’s internal real-time clock (RTC) to control the overall pattern of operation. The timer is set to a specific delay corresponding to the sensing interval. When the timer expires, the sensor will wake up and begin an ultrasonic range measurement. When the measurement is complete, the sensor will notify the remote host device by asserting the INT line.
    - Free-Running mode may only be used by individual sensors operating independently. Multi-sensor configurations must use one of the triggered modes described below.
    - The internal RTC used in Free-Running mode provides good accuracy, but it is not as stable as a crystal-controlled oscillator typically found on a microcontroller board. Therefore, hardware-triggered mode (see next section) should be used for critical timing applications.
- Hardware Triggered Mode
    - INT pin is used bi-directionally
    - Remains in an idle condition until triggered by pulsing the INT pin
    - Measurement will start with sub-microsecond latency

    - Most useful for synchronizing several transceivers
    - Hardware-Triggered Transmit/Receive Mode
        - In many applications, the ultrasonic measurements require more exact timing than the sensor's internal RTC provides in Free-Running mode, or the sensor operation needs to be coordinated with other application activities. In these cases, the sensor's measurement cycle can be initiated by using a hardware trigger, in which the remote host device asserts and then releases the INT line. When the sensor detects that the INT line has been asserted, it will begin a measurement cycle.
        - The most typical mode for a single sensor is Hardware-Triggered Transmit/Receive (Tx/Rx). In this mode, the sensor will generate an ultrasonic pulse when it is triggered by the INT line from the host. The sensor then listens for a response (echo) for an amount of time based on the maximum range setting of the device. When the measurement cycle is complete, the sensor will notify the host by asserting the INT line. Note that the INT line operates in two directions when used in hardware-triggered mode – first as an input to the sensor (output from host) to initiate the measurement and then as an output from the sensor (input to host) for the measurement-complete notification.
        - Generally, the host application will repeatedly trigger the sensor based on the host's periodic timer that can maintain an accurate sensing interval. Conversely, the application may wait until specific conditions are met, then initiate an isolated measurement.
    - Hardware-Triggered Receive-Only Mode
        - When more than one ultrasonic sensor is used, they may be configured so that one device operates in hardware-triggered Tx/Rx mode as described above, and one or more other sensors operate in hardware-triggered Receive-Only mode (Rx-only). In this case, all sensors are triggered by the remote host simultaneously via their INT lines. The single Tx/Rx node generates an ultrasonic pulse and listens for an echo as normal. All Rx-only nodes will simultaneously begin their own listening periods, but without sending an ultrasonic pulse. Instead, the Rx-only sensors simply wait to detect the pulse that was sent from the Tx/Rx sensor (either directly, or as an echo off another object).
        - When each sensor completes its measurement cycle, it will notify the remote host by asserting its INT line.
- Standby Mode
    - Recommended way to ender low power standby mode
    - Use free-running mode with PERIOD=0 and TICK_INTERVAL=2048.

2.4.3 CH101 Features

- Short-range mode:
    - Measures range from 4 cm to 25 cm
    - Uses a shorter TX pulse
    - Firmware can be switched in 60 ms
- Stationary target rejection:
    - Internal high-pass filter to ignore stationary targets, useful for motion sensing

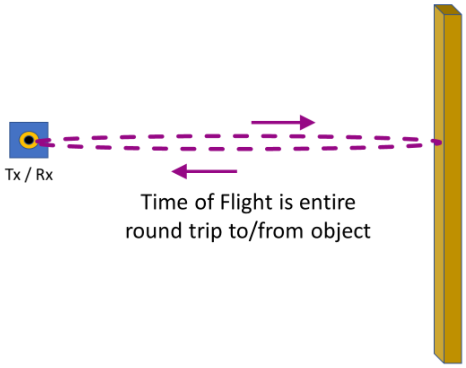
2.5 SENSING CONFIGURATIONS

A CH101 device may be used alone or in combination with one or more other sensors. A single sensor always operates in “Pulse-Echo” mode, in which it both transmits and receives an ultrasound pulse. Multiple sensors may operate in “Pitch-Catch” mode, in which one sensor transmits the ultrasound pulse, and one or more sensors receive it. This section explains these different configurations.

2.5.1 Single Sensor Pulse-Echo

The most basic configuration is a single CH101 device. In this arrangement, the sensor will both transmit and receive ultrasound to perform the measurements. The device will listen for an echo of its own ultrasound signal, calculate the ToF for the received echo, then notify the host system that the measurement has completed. This is often simply called “Pulse-Echo” operation.

Figure 2-8. Single-Sensor Pulse-Echo

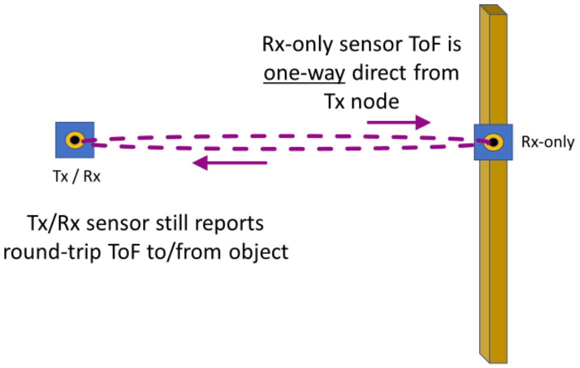


2.5.2 Multi-Sensor Direct Pitch-Catch

In other applications, multiple CH101 devices may be used together, in what is often called "Pitch-Catch" operation. One sensor generates an ultrasonic pulse and waits for an echo (Tx/Rx mode), as in the single-device configuration. One or more other sensors are operated in "receive-only" (Rx-only) mode and do not generate ultrasonic pulses. They simply listen for the pulse from the first device. All devices (the transmitting sensor and all receive-only sensors) are synchronized so that the receive-only nodes will start their sampling when the first sensor transmits. All devices then process the received signal, calculate the ToF, and report to the host system.

There are two basic approaches to using a pair of sensors together (one transmitting and another receiving). In some cases, the two sensors are attached to two different objects, and the distance being measured is the direct distance between the two objects. In this situation, the important data values are the range measurements from the receive-only device. The ToF measured in this case is the one-way, direct path between the transmitting and receiving sensors. This mode of operation gives the best performance in terms of measurement accuracy and stability.

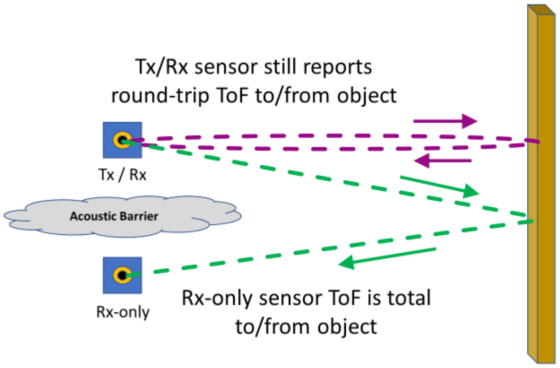
Figure 2-9. Direct Pitch-Catch



2.5.3 Multi-Sensor Reflected Pitch-Catch

The other way two or more sensors may be used in Pitch-Catch operation is for the devices to be mounted to the same object, with the ultrasonic signal reflected off another object. The receive-only sensor will measure and report the total ToF for the path from the transmitting sensor, bouncing off the target object, and then back to the receiving sensor. Depending on the relative positions of the two sensors and the target object, this distance may differ significantly from a simple single-sensor echo path. Note the use of an acoustic barrier to help prevent the ultrasound pulse from travelling directly between the sensors.

Figure 2-10. Reflected Pitch-Catch



2.6 SENSOR SAMPLING AND OPERATING FREQUENCY

When examining the sample timing for a CH101 device, there are two distinct time bases to consider. The first, slower time-base is the rate at which the sensor begins new measurement cycles (e.g. 10 measurements/sec, 30 measurements/sec, etc.). This is the sample rate that is usually most important to a sensing application, because it determines how often the measurement data will be updated. If the sensor is operating in Free-Running mode, this slow time-base is generated by the sensor's on-chip real-time clock (RTC). In the hardware triggered modes, an external host maintains the slow time-base and triggers the sensor(s) at the appropriate time.

The second, fast time-base is the internal sample rate used within an individual ultrasonic measurement. The received ultrasound is first demodulated from the ultrasonic transmit frequency to the baseband, and each measurement cycle consists of many individual samples of the demodulated baseband signal. The timing of this internal baseband sampling is a function of the sensor's operating frequency. In normal range-finding mode, the baseband sample rate, f_s, is equal to the sensor's ultrasonic operating frequency, f_{op}, divided by 8,

$$f_s = f_{op} / 8.$$

For CH101 devices, the operating frequency is generally around 175 kHz, while CH201 devices operate around 85 kHz, so the typical baseband sample rate is around 22 kHz for CH101 and around 11 kHz for CH201. CH101 also has a special short-range range-finding mode that uses a higher baseband sample rate, $f_{s,short\text{-}range} = f_{op} / 2$, for better performance at short range.

The specific operating frequency used by an individual sensor is set during power-up and initialization, during the device's built-in self-test (BIST). The frequency value may be calculated from device registers read over I²C. In SonicLink, each sensor's frequency is displayed in the console window. Embedded applications may obtain the sensor frequency using the Chirp API and driver.

Because the timing of the individual samples within a measurement is based on the sensor's specific operating frequency, the exact sample timing will vary slightly between devices. This difference becomes significant when the sample offsets (in time) need to be converted to physical distance, because the physical distance represented by a given sample index will vary slightly. Therefore, the device's operating frequency is a component in the calculations when interpreting the reported range value from the sensor, which is expressed in terms of a sample index.

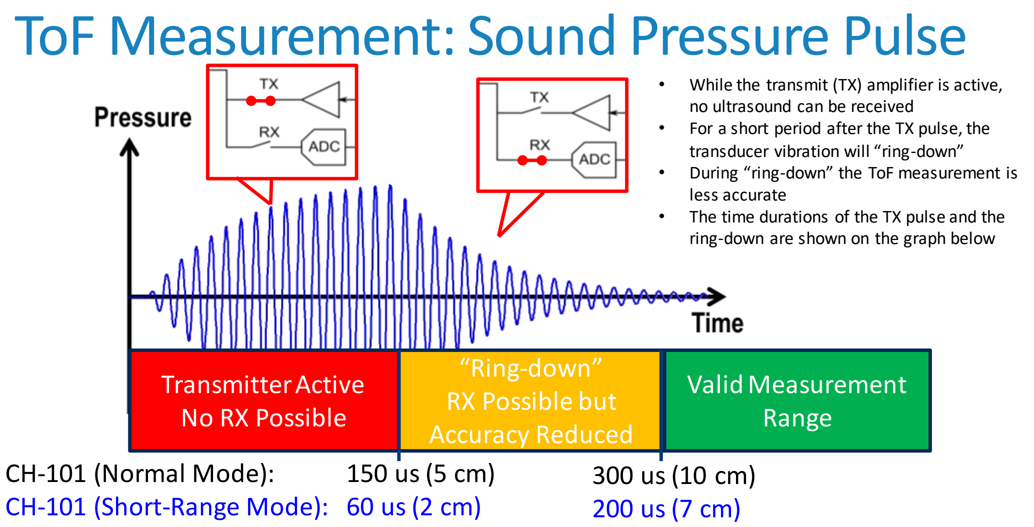
The internal CH101 RTC is calibrated against a known time base during device initialization. This is done by applying a pulse of known duration (typically 100 milliseconds) to the sensor's INT line. The device will return a clock count value which corresponds to the calibration pulse length. This count value is later used in the range calculation, along with the duration of the calibration pulse, to establish an accurate conversion between the internal sensor sample offsets and physical distance.

2.7 ULTRASONIC SENSOR OPERATION FUNDAMENTALS

2.7.1 Time of Flight Measurement

- The Sensor PMUT is excited with a Transducer Vibration to generate a sound pressure pulse
- However, for a short time after the Transducer vibration, the sensor cannot effectively sense a return signal due to the continued vibration of the PMUT. This period of time is known as "Ring-down". A state where the sensor membrane is still vibrating from the transmit pulse and cannot accurately receive a return echo pulse. Once the vibration level is BELOW the expected sensed vibration of a returned echo, the sensor is usable sensing state.

Figure 2-11. ToF measurement



ToF Measurement: Sound Pressure Pulse

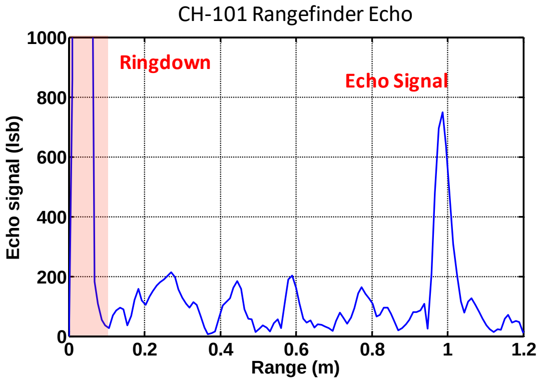
- While the transmit (TX) amplifier is active, no ultrasound can be received
- For a short period after the TX pulse, the transducer vibration will "ring-down"
- During "ring-down" the ToF measurement is less accurate
- The time durations of the TX pulse and the ring-down are shown on the graph below

Transmitter Active No RX Possible	"Ring-down" RX Possible but Accuracy Reduced	Valid Measurement Range

CH-101 (Normal Mode):	150 us (5 cm)	300 us (10 cm)
CH-101 (Short-Range Mode):	60 us (2 cm)	200 us (7 cm)

- The time it takes the Sensor to "Ring-down" is the ineffective close proximity sensing distance of the sensor. That is the reason a sensor as a minimum range sensing greater than 2 cm. This equates to the sensor not effective for measurement the first 60 us after a Tx Pulse. The following range-based graph shows the Equivalent distance of a ToF plot.

Figure 2-12. Rangefinder plot



2.7.2 Detecting and Echo response

- The sensor operation is pulsing a Pressure signal and measuring the response signal in the ToF interval that correlates to the range (distance) that is being sensed.
- Anything before or after the expected ToF interval is either spurious noise from an unwanted reflection or an echo from a longer than expected distance.
- If the initial signal is low Amplitude, the response will be lower and not much above ambient noise and therefore hard to differentiate.
- The Threshold or Amplitude level a certain level of magnitude above noise or ambient is an indication of a reflected surface or object.

Figure 2-13. ToF Measurement: Threshold Crossing

ToF Measurement: Threshold Crossing

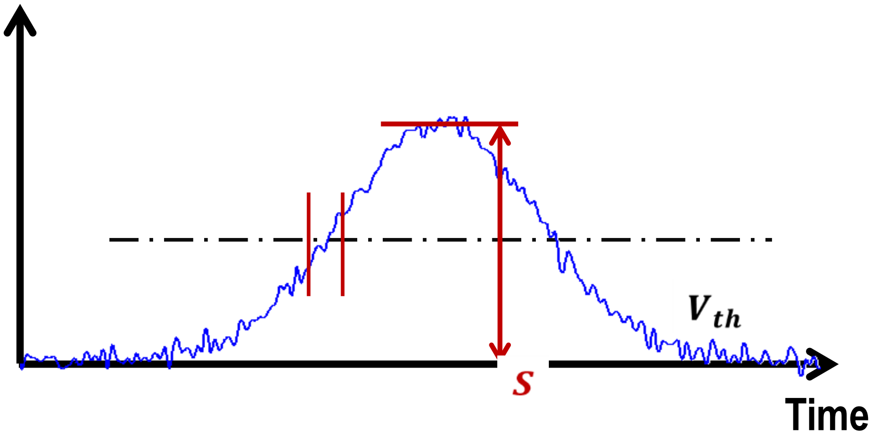
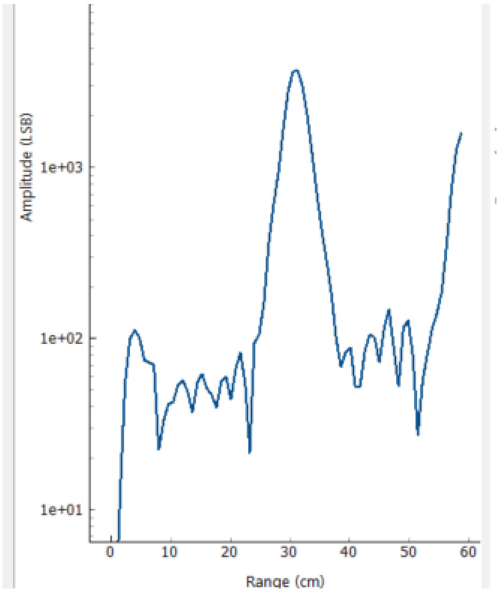


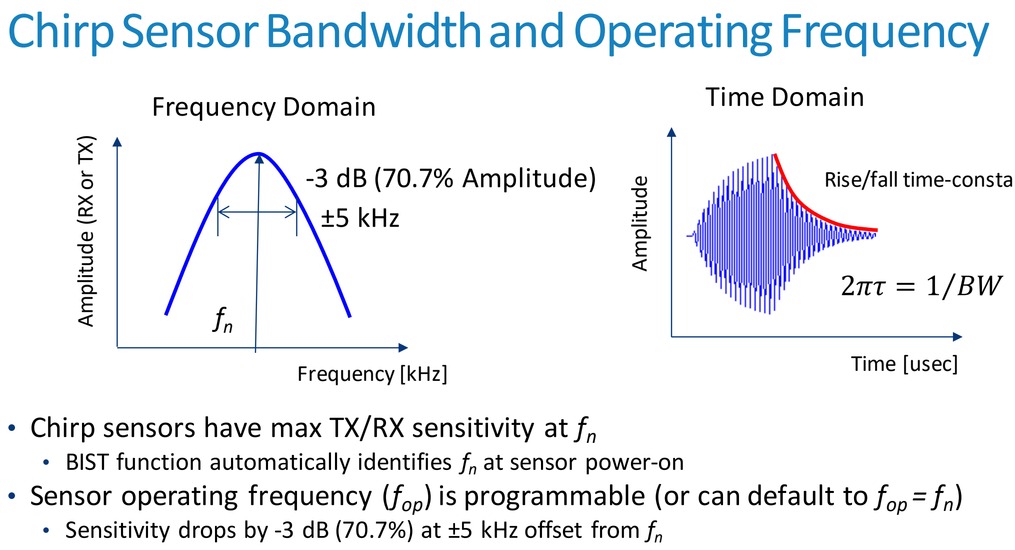
Figure 2-14. Range versus Amplitude plot



2.7.3 CH101 Sensor Bandwidth and Operating Frequency

- Operating Frequency of Sensors can affect the sensing range of a unit.
- For lower minimum sensing application (ie 3-4 cm) it is best to use a higher operating frequency sensor so to have enough bandwidth (sensing interval) soon after the Tx pulse is initiated.
- For higher maximum sensing applications, (ie 1 m) it is best to use a lower operating frequency sensor so to maximize the time to sense to be later in the cycle.
- The CH101 sensors are Binned to operating Frequency ranges and which bin is determined by application.

Figure 2-15. Bandwidth and operating frequency



Chirp Sensor Bandwidth and Operating Frequency

- Chirp sensors have max TX/RX sensitivity at f_n
  - BIST function automatically identifies f_n at sensor power-on
- Sensor operating frequency (f_{op}) is programmable (or can default to $f_{op} = f_n$)
  - Sensitivity drops by -3 dB (70.7%) at ±5 kHz offset from f_n

2.7.4 Frequency Matching for Pitch & Catch (2 Sensors)

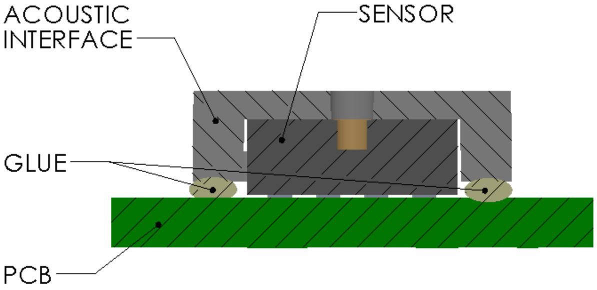
- Operating Frequency must match when using 2 sensors in a pitch catch operation.
- The matching Frequency ensures timing matches for any algorithm calculations

3 THE CH101-BASED MODULES

3.1 BASIC MODULE OVERVIEW

A module consists of the CH101 Sensor surface mounted to a PCBA with an acoustic interface (horn). For applications that need protection from a certain contaminate, the module will have a Particle Ingress Filter (PIF) sandwiched in between the Sensor IC and the adhered acoustic interface.

Figure 3-1. CH101 module stack-up



Please refer to AN-000158 CH101 Mechanical Integration Guide for detailed module and module integration information.

3.1.1 Acoustic Interfaces

An acoustic interface is required for sound output performance:

- Large acoustic impedance differences between the PMUT transducer and the air results in energy not being transferred efficiently to the air
- An acoustic interface in front of the sensor package port hole better matches the impedance improving transfer of sound energy to the air
- The acoustic interface dimensions and geometry dictate the FoV

3.1.2 Two Categories of Acoustic Interfaces: Horns and Tubes

- Tubes:
    - Specific length and diameter
    - Provided smallest hole opening for industrial designs
    - Always 180 degrees FoV (Omnidirectional)
    - Narrowband (only works well over a small frequency range, compared to horns)
- Horns:
    - More complex dimensions: Throat, mouth, length, profile
    - Create a focused beam
    - Provide narrower FoV
    - In General:
        - Larger mouth opening produce narrower FoV
        - Longer horn length typically increases output pressure

Figure 3-2. Horn profile

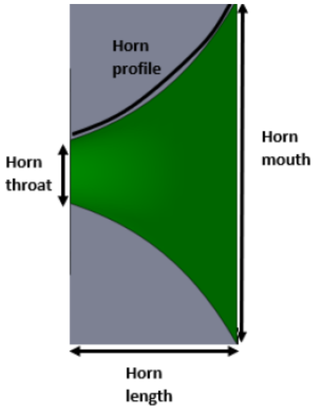
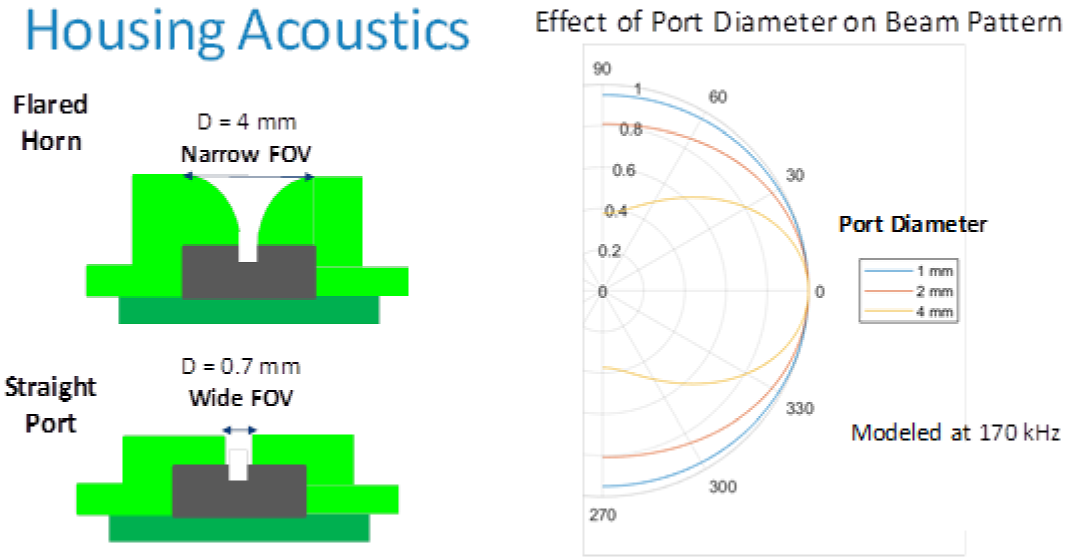


Figure 3-3. CH101 Housing acoustics and beam pattern



3.2 EV_MOD_CH101-03-01 (OMNIDIRECTIONAL MODULE) REFERENCE DESIGN

The EV_MOD_CH101-03-01 is a module reference design for 180 Deg FoV horn design that is also available for evaluations.

Please refer to AN-000231 EV_MOD_CH101 Evaluation Module User Guide

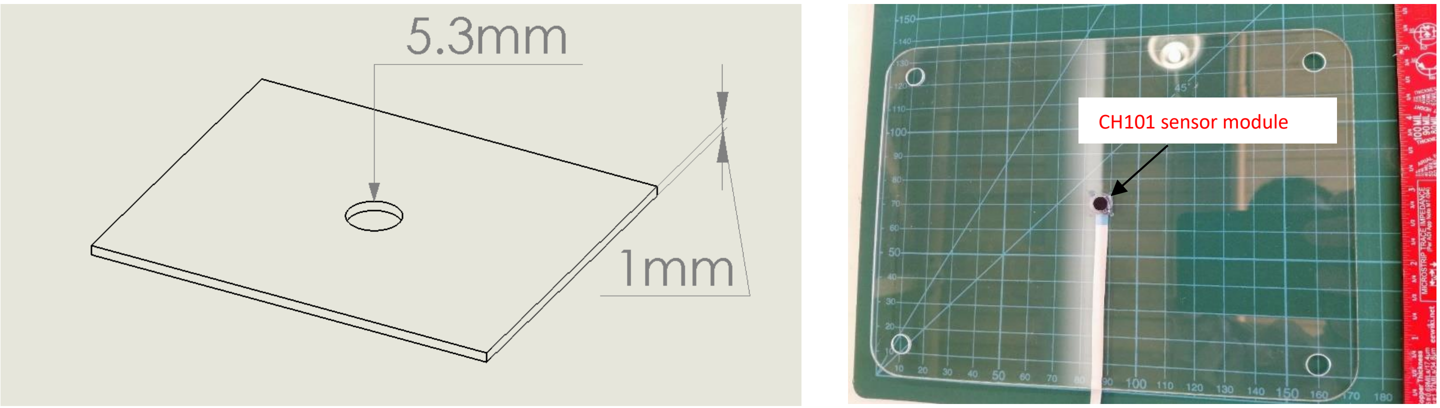
Please refer to PB-000082 AH-10100-180180 Acoustic Housing Brief

Please refer to PB-000081 AH-10133-045045MR Acoustic Housing Brief

3.2.1 Sensor Mounting

To achieve the best acoustic performance, users are recommended to mount the EV_MOD_CH101 module in a flat mounting plate. An example mounting plate is shown in Figure 3-4, where the sensor has been inserted into a 5.3 mm diameter hole has been drilled in a 1 mm thick plastic plate measuring 135 mm x 175 mm.

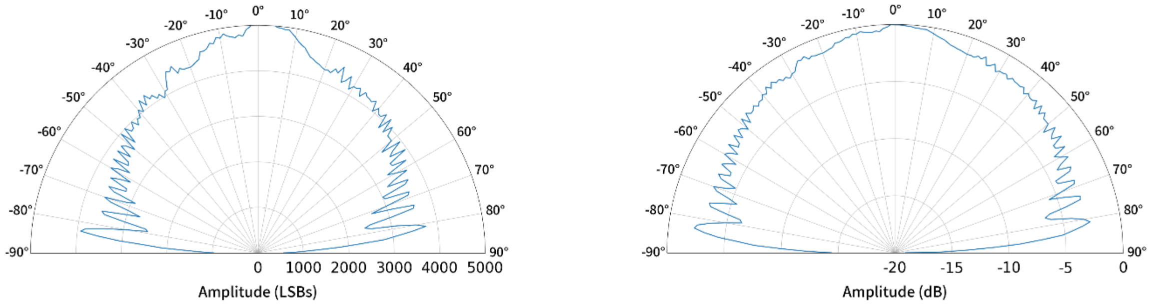
Figure 3-4. EV_MOD_CH101 mounting



3.2.2 Beam Patterns

Pulse-echo beam-pattern plots of the EV_MOD_CH101 module are shown in Figure 3-5. This beam-pattern was measured by placing a 1m^2 target at a 30 cm distance from the EV_MOD_CH101 module and recording the ToF amplitude as the sensor is rotated 180°. The plots are shown in both raw LSB units and normalized dB units, where 0 dB corresponds to the peak amplitude (5000 LSB) recorded on-axis. Chirp defines the FoV as the full-width at half-maximum (FWHM) of the beam pattern; in other words, the FoV is the range of angles over which the amplitude remains above half the peak amplitude (or -6 dB). When mounted in the recommended plate, the sensor's FoV is approximately 180° and the pulse-echo amplitude diminishes relatively smoothly from 0° to ±80°.

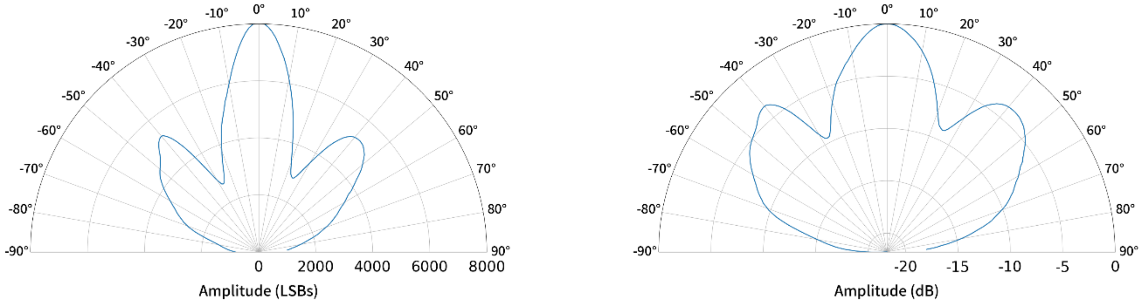
Figure 3-5. EV_MOD_CH101 Pulse-echo beam-pattern plots



For comparison, the pulse-echo beam-pattern plot measured for an EV_MOD_CH101 when tested without a sensor mounting plate is shown in Figure 3-6. The beam pattern has three lobes: a main lobe and two side-lobes that are centered at ±45°. The sensor device will work well for detecting on-axis targets, but targets located at ±25° will have approximately 70% lower (-10 dB) amplitude, possibly resulting in poor range-finding performance.

Figure 3-6. EV_MOD_CH101 Beam pattern measurements (w/o a mounting plate)

(raw linear LSB units left, normalized dB right)



3.3 EV_MOD_CH101-03-02 (45 DEG FOV MODULE) REFERENCE DESIGN

The EV_MOD_CH101-03-02 is a module reference design for 45 Deg FoV horn design that is also available for evaluations.

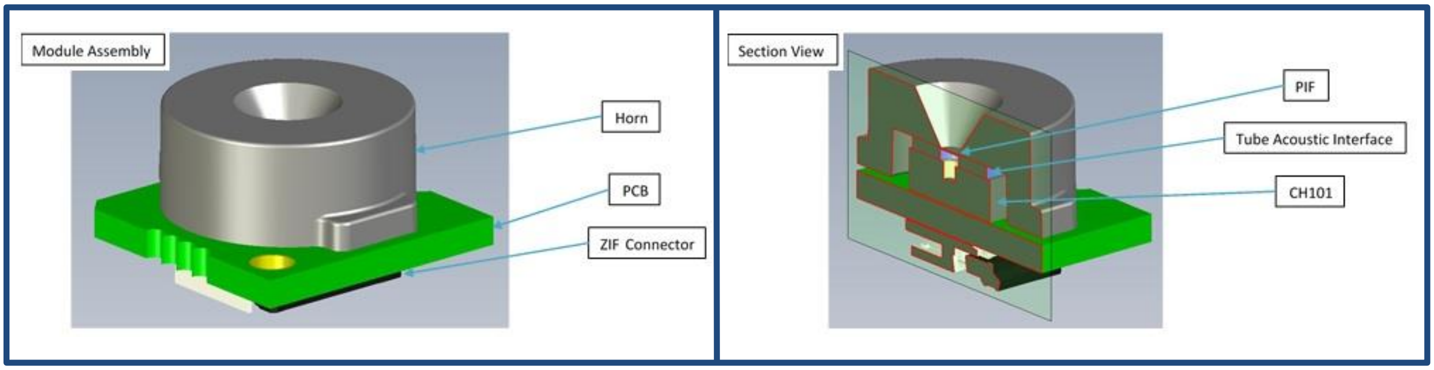
3.3.1 BOM & Dimensions

EV_MOD_CH101 module consists of:

1. **Horn**: Controls acoustic beam (FoV) with horn design profile
2. **PCB with ZIF connector**: Used to mount and communicate with CH101
3. **CH101**: Ultrasonic transceiver rangefinder
4. **Particle Ingress Filter (PIF)**: Cover over CH101 to protect from dust, liquid, or contaminants
5. **Tube acoustic interface**: Optimized interface to improve sound performance

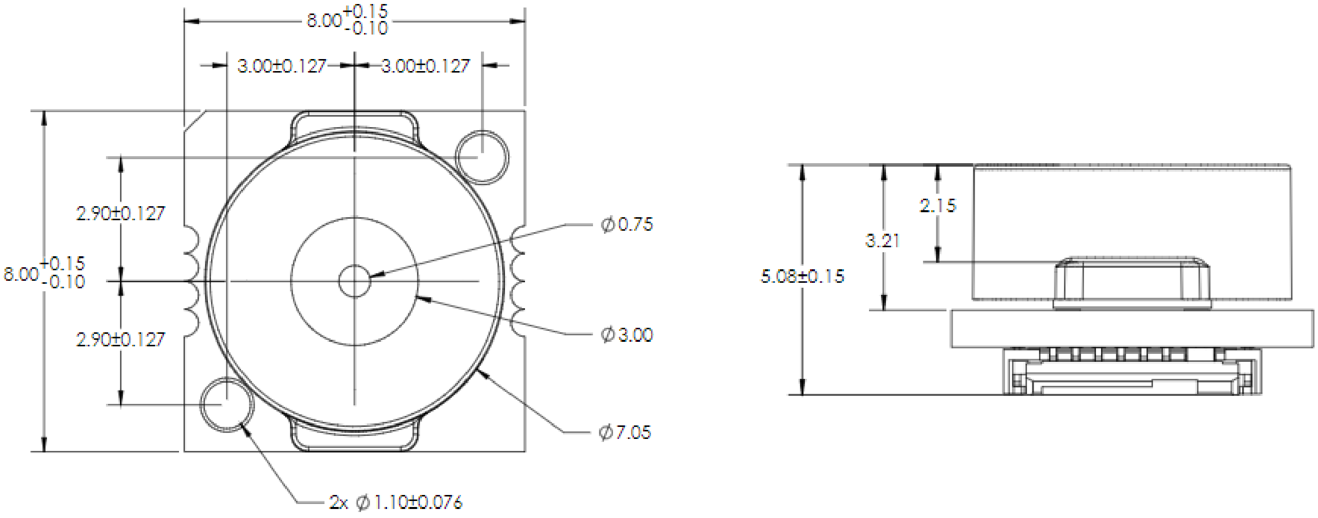
Note: Stack and BOM may differ for each application of module

Figure 3-7. EV_MOD_CH101-03-02 module BOM with a 45-degree FoV and PIF



In Figure 3-8, the module dimensions will be dependent on the type of horn being used. Datasheets provide module dimensions for each specific ultrasonic ToF range sensor available.

Figure 3-8. CH101-03-02 module dimensions with 45-degree FoV and PIF



3.3.2 Object Detection

Detecting the presence of objects or people can be optimized via software by setting the sensor's full-scale range (FSR). The user may set the maximum distance at which the sensor will detect an object. FSR values refer to the one-way distance to a detected object.

In practice, the FSR setting controls the amount of time that the sensor spends in the listening (receiving) period during a measurement cycle. Therefore, the FSR setting affects the time required to complete a measurement. Longer full-scale range values will require more time for a measurement to complete.

Ultrasonic signal processing using the MOD_CH101-03-02's General Purpose Rangefinder (GPR) Firmware will detect echoes that bounce off the first target in the FoV. The size, position, and material composition of the target will affect the maximum range at which the sensor can detect the target. Large targets, such as walls, are much easier to detect than smaller targets. Thus, the associated operating range for smaller targets will be shorter. The range to detect people will be affected by a variety of factors such as a person's size, clothing, orientation to the sensor, and the sensor's FoV. In general, given these factors, people can be detected at a maximum distance of 0.7m away from the MOD_CH101-03-02 sensor.

3.3.3 Mounting Requirements

It is important to meet all mounting requirements and follow mounting suggestions. The mechanical integration guide can be reviewed for a deeper dive into the module assembly and further explanation on the requirements listed below.

Please refer to AN-000158 CH101 Mechanical Integration Guide

- No reflecting objects in the FoV

Figure 3-9. Example of improper enclosure/housing in 45deg module FoV

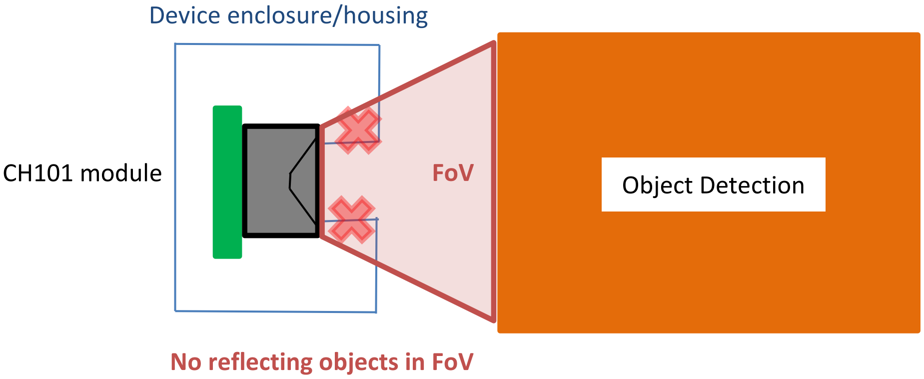
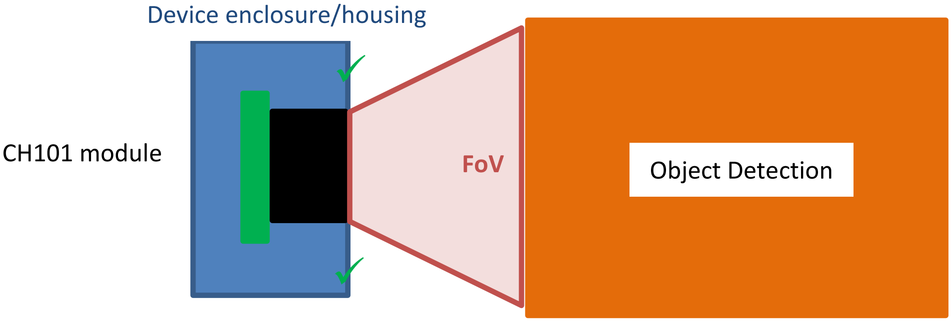
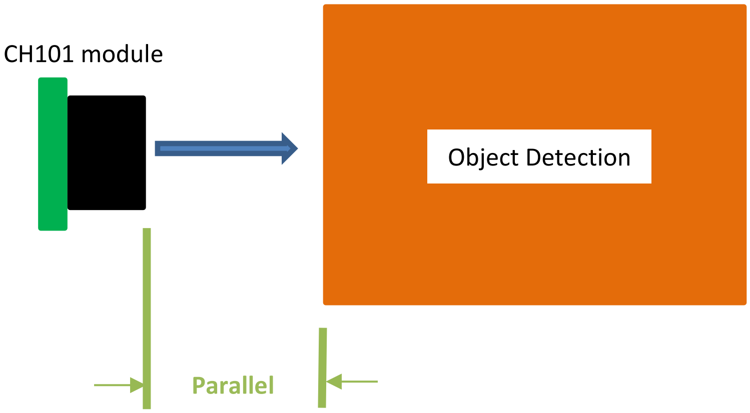


Figure 3-10. Example of proper enclosure/housing not in FoV



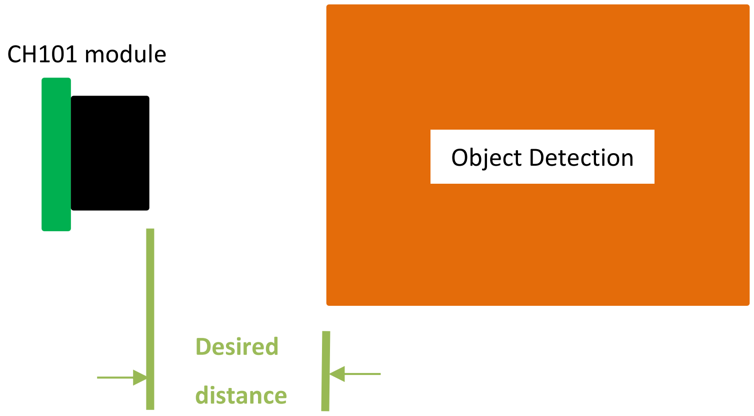
- Parallel to intended direction for maximum signal

Figure 3-11. Example of parallel module to intended FoV direction



- Set to desired module distance of detecting range (in some cases)

Figure 3-12. Example of setting distance with intended FoV range

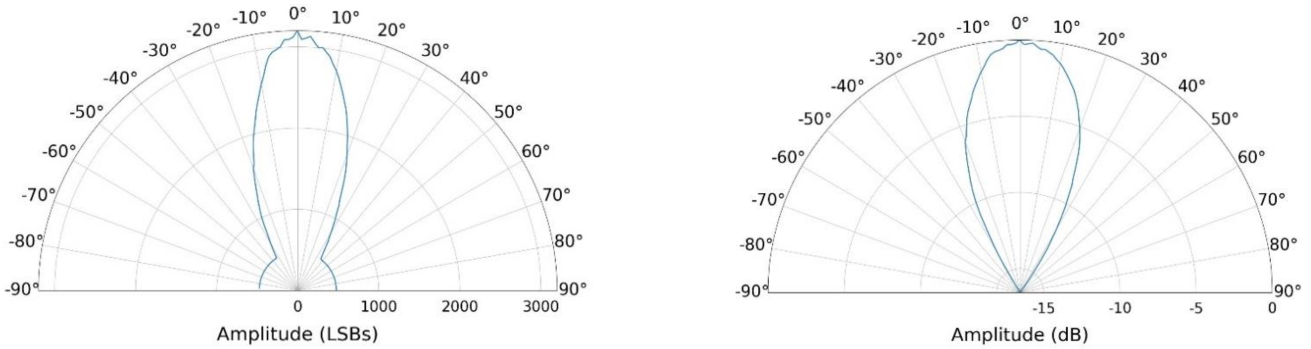


3.3.4 Beam Pattern

Typical Beam Pattern – MOD_CH101-03-02 with a 45° FoV acoustic housing module

(Measured with a 1m^2 flat plate target at a 30 cm range)

Figure 3-13. MOD_CH101-03-02 beam-pattern plots



4 MODULE TEST

Please refer to AN-000169-Ultrasonic-Module-Pulse-Echo-Test-Procedure-v1.1 for details on Module Testing

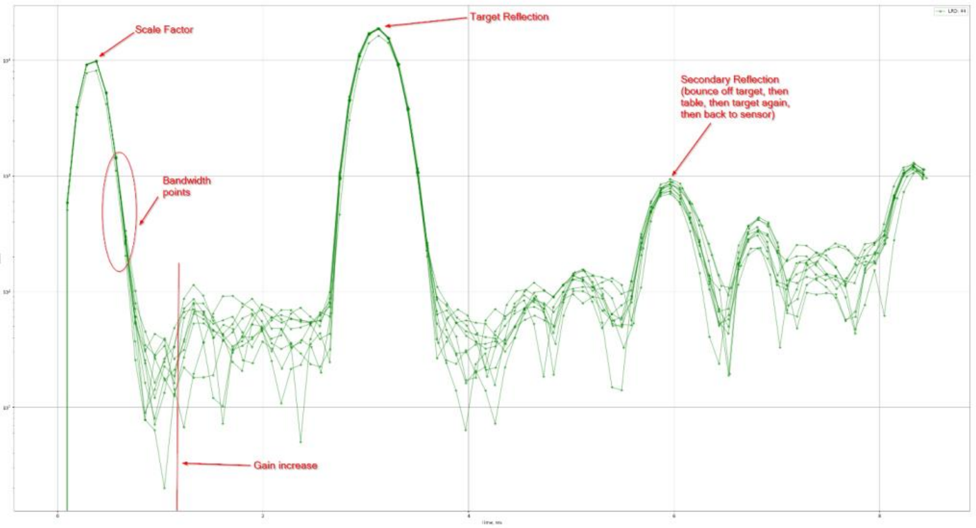
4.1 CHIRP BUILT-IN SELF-TEST (BIST): WHAT IT MEASURES

BIST measures the frequency response parameters of the CH101 transceiver.

- Natural frequency (fn)
  - Definition: the frequency where the CH101 has maximum transmit/receive amplitude
  - Importance: CH101 performance is best within an 8 kHz band surrounding fn
- Bandwidth (BW)
  - Definition: BW determines the rise-time and fall-time of each transmitted ultrasonic pulse
  - Importance: CH101 rise-time must be fast enough for each TX (or RX) pulse to reach full amplitude
- Scale-factor (SF)
  - Definition: SF measures the TX or RX amplitude of CH101
  - Importance: the CH101 must have sufficient amplitude

4.2 FULL PC BASED MODULE TEST

Figure 4-1. Example Trace



- **Frequency:** This test will ensure all parts are operate within the specified frequency. This is most important if using as Pitch-Catch as the parts need to be in sync.
- **Bandwidth/Ring down time:** Calculates when sensing can start after signal has been transmitted. If the range of bandwidth varies greatly, then the accuracy range will be off.
- **Range:** Distance measured in mm from the known target.
  - Sensing starts after a specified time. The number of clock cycles received will calculate the range.
- **Scale Factor:** Measures where the ringdown is the loudest. Gives an idea how loud the sensor is and give a relative scale for how much signal will be received.

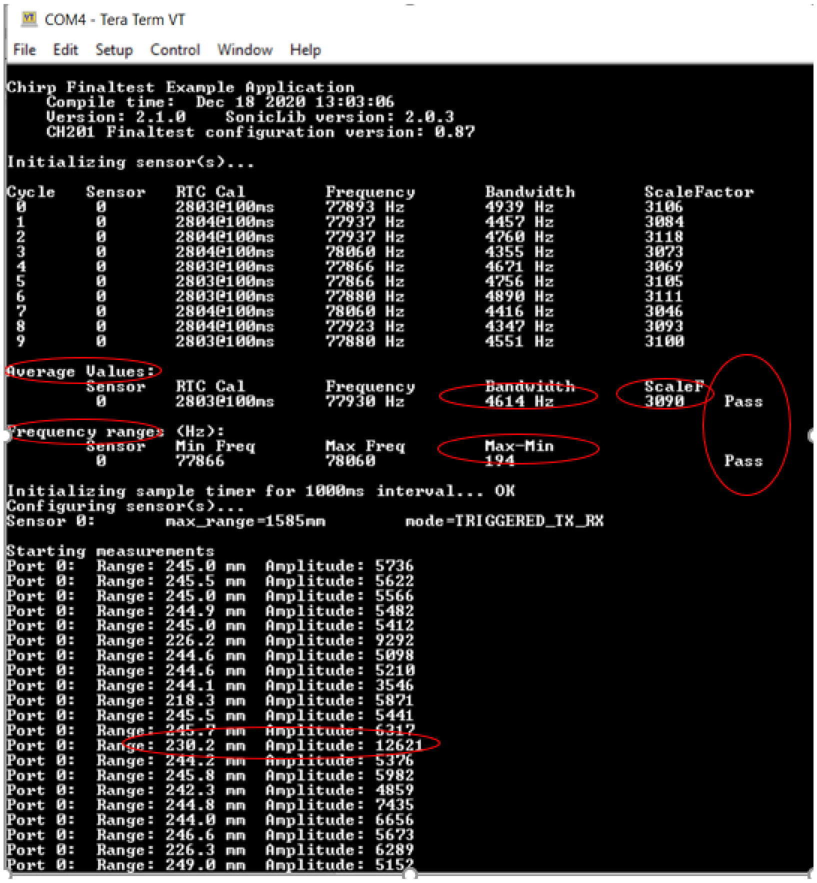
Table 4-1. Module Test Software

Software	Definition
SonicLink vX.XX.X.X	Ranging tool used with TDK/Chirp SmartSonic board
SmartSonic_FinaltestExample_vX_X_X	Module Test

4.2.1 Example of a good part: FinalTest Pass

- Figure 4-2 is an example output of a passing Module Test, also referred to FinalTest.

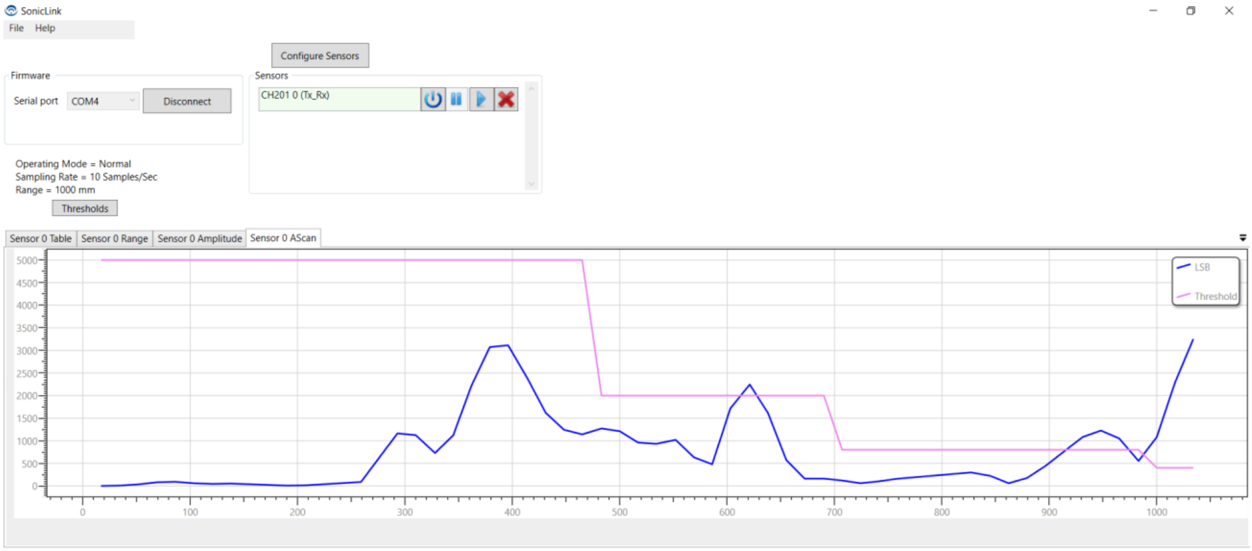
Figure 4-2. FinalTest Pass: Output example



```
Chirp Finaltest Example Application
    Compile time:  Dec 18 2020 13:03:06
    Version: 2.1.0    SonicLib version: 2.0.3
    CH201 Finaltest configuration version: 0.87

Initializing sensor(s)...

Cycle   Sensor   RTC Cal          Frequency       Bandwidth       ScaleFactor
 0        0      2803@100ms       77893 Hz        4939 Hz         3106
 1        0      2804@100ms       77937 Hz        4457 Hz         3084
 2        0      2804@100ms       77937 Hz        4760 Hz         3118
 3        0      2804@100ms       78060 Hz        4355 Hz         3073
 4        0      2803@100ms       77866 Hz        4671 Hz         3069
 5        0      2803@100ms       77866 Hz        4756 Hz         3105
 6        0      2803@100ms       77880 Hz        4890 Hz         3111
 7        0      2804@100ms       78060 Hz        4416 Hz         3046
 8        0      2804@100ms       77923 Hz        4347 Hz         3093
 9        0      2803@100ms       77880 Hz        4551 Hz         3100

Average Values:
        Sensor   RTC Cal          Frequency       Bandwidth       ScaleF
          0      2803@100ms       77930 Hz        4614 Hz         3090      Pass

Frequency range: (Hz):
        Sensor   Min Freq         Max Freq        Max-Min
          0      77866            78060           194                       Pass

Initializing sample timer for 1000ms interval... OK
Configuring sensor(s)...
Sensor 0:       max_range=1585mm        mode=TRIGGERED_TX_RX

Starting measurements
Port 0:  Range: 245.0 mm  Amplitude: 5736
Port 0:  Range: 245.5 mm  Amplitude: 5622
Port 0:  Range: 245.0 mm  Amplitude: 5566
Port 0:  Range: 244.9 mm  Amplitude: 5482
Port 0:  Range: 245.0 mm  Amplitude: 5412
Port 0:  Range: 226.2 mm  Amplitude: 9292
Port 0:  Range: 244.6 mm  Amplitude: 5098
Port 0:  Range: 244.6 mm  Amplitude: 5210
Port 0:  Range: 244.1 mm  Amplitude: 3546
Port 0:  Range: 218.3 mm  Amplitude: 5871
Port 0:  Range: 245.5 mm  Amplitude: 5441
Port 0:  Range: 245.7 mm  Amplitude: 6317
Port 0:  Range: 230.2 mm  Amplitude: 12621
Port 0:  Range: 244.2 mm  Amplitude: 5376
Port 0:  Range: 245.8 mm  Amplitude: 5982
Port 0:  Range: 242.3 mm  Amplitude: 4859
Port 0:  Range: 244.8 mm  Amplitude: 7435
Port 0:  Range: 244.0 mm  Amplitude: 6656
Port 0:  Range: 246.6 mm  Amplitude: 5673
Port 0:  Range: 226.3 mm  Amplitude: 6289
Port 0:  Range: 249.0 mm  Amplitude: 5152
```

- An AScan without any object in front, the amplitude is around or below the threshold in the 3000 range.

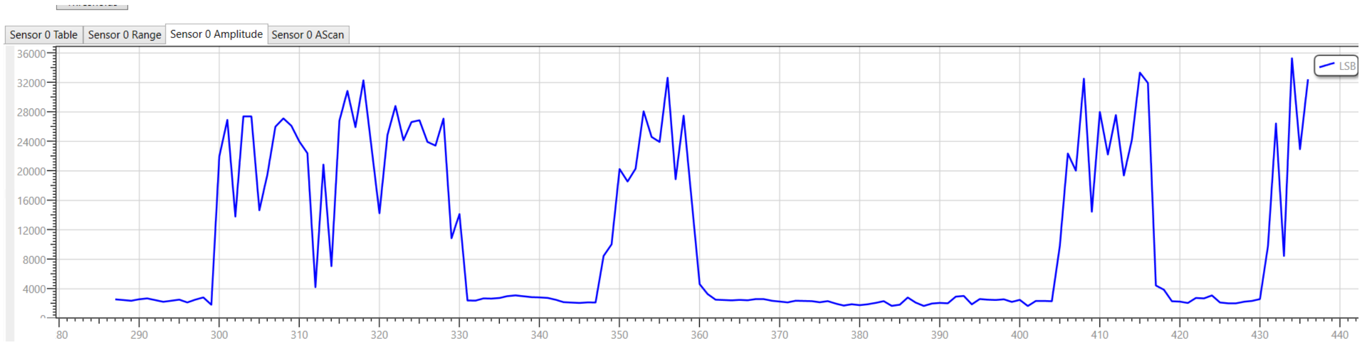
Figure 4-3. FinalTest Pass: Ascan without object



Operating Mode = Normal
Sampling Rate = 10 Samples/Sec
Range = 1000 mm

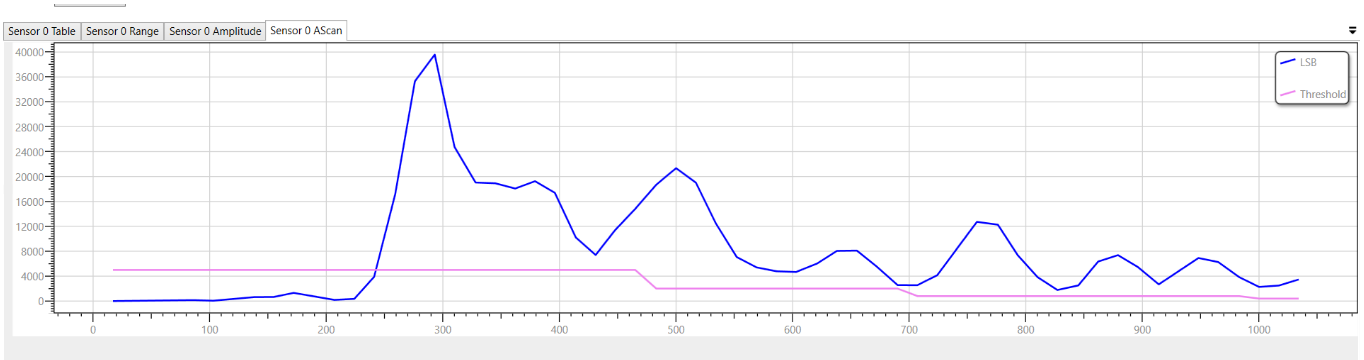
- When an object is placed in front, the amplitude increases significantly.

Figure 4-4. FinalTest Pass: Ascan with object



- An Ascan to show Amplitude vs Distance (mm)

Figure 4-5. FinalTest Pass: Ascan Amplitude vs Distance



4.2.2 Example of a bad part: FinalTest Fail

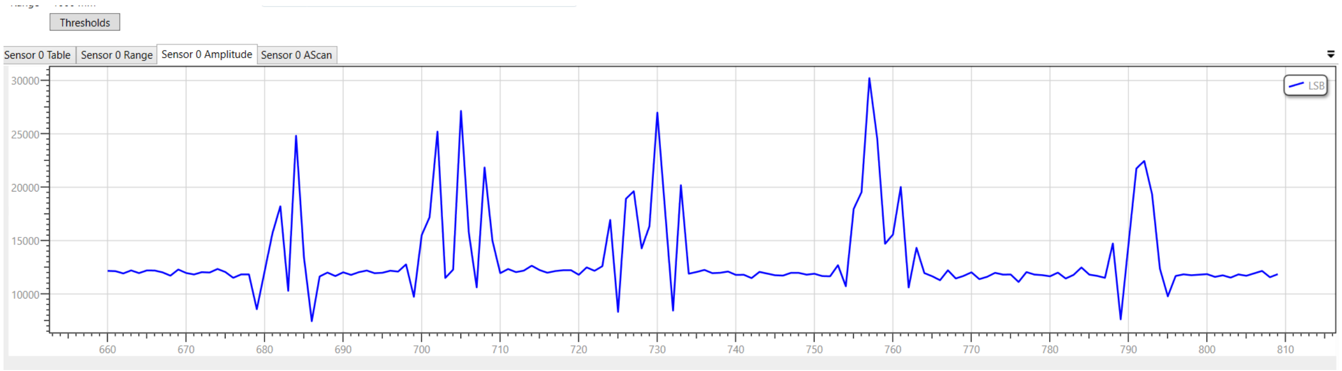
- Figure 4-6 is an example output of a failing FinalTest.
- The bandwidth and scale factor are both out of range. Since bandwidth is low, the range measurement will occur sooner than it should, therefore measuring in the early ringdown period resulting incorrect range. Note the amplitude change when starting measurements, regardless of the amplitude, the range reporting doesn't change very much.

Figure 4-6. FinalTest Fail: bandwidth out of range

```
Chirp Finaltest Example Application
    Compile time:  Dec 18 2020 13:03:06
    Version: 2.1.0    SonicLib version: 2.0.3
    CH201 Finaltest configuration version: 0.87

Initializing sensor(s)...

Cycle   Sensor   RTC Cal          Frequency       Bandwidth       ScaleFactor
 0       0       2859@100ms       72344 Hz        1293 Hz         14457
 1       0       2860@100ms       72410 Hz        1316 Hz         14391
 2       0       2859@100ms       72456 Hz        1317 Hz         13707
 3       0       2859@100ms       72344 Hz        1315 Hz         14423
 4       0       2859@100ms       72470 Hz        1329 Hz         13689
 5       0       2860@100ms       72410 Hz        1294 Hz         14315
 6       0       2859@100ms       72470 Hz        1317 Hz         13594
 7       0       2860@100ms       72396 Hz        1282 Hz         14152
 8       0       2859@100ms       72344 Hz        1315 Hz         14277
 9       0       2860@100ms       72410 Hz        1316 Hz         14241

Average Values:
        Sensor   RTC Cal          Frequency       Bandwidth       ScaleF
         0       2859@100ms       72405 Hz        1309 Hz         14124    FAIL

Frequency ranges (Hz):
        Sensor   Min Freq         Max Freq        Max-Min
         0       72344            72470           126                      Pass

Initializing sample timer for 1000ms interval... OK
Configuring sensor(s)...
Sensor 0:       max_range=1705mm        mode=TRIGGERED_TX_RX

Starting measurements
Port 0:  Range: 51.0 mm  Amplitude: 3652
Port 0:  Range: 51.1 mm  Amplitude: 3870
Port 0:  Range: 51.1 mm  Amplitude: 3541
Port 0:  Range: 51.5 mm  Amplitude: 3475
Port 0:  Range: 50.8 mm  Amplitude: 3870
Port 0:  Range: 50.6 mm  Amplitude: 4291
Port 0:  Range: 50.6 mm  Amplitude: 3480
Port 0:  Range: 50.7 mm  Amplitude: 3368
Port 0:  Range: 50.9 mm  Amplitude: 3605
Port 0:  Range: 54.8 mm  Amplitude: 22116
Port 0:  Range: 48.2 mm  Amplitude: 26275
Port 0:  Range: 50.5 mm  Amplitude: 3638
Port 0:  Range: 50.4 mm  Amplitude: 3581
Port 0:  Range: 48.2 mm  Amplitude: 6556
Port 0:  Range: 46.6 mm  Amplitude: 21775
Port 0:  Range: 50.9 mm  Amplitude: 21400
Port 0:  Range: 50.1 mm  Amplitude: 2474
Port 0:  Range: 48.2 mm  Amplitude: 29572
Port 0:  Range: 51.8 mm  Amplitude: 2787
Port 0:  Range: 51.2 mm  Amplitude: 3324
Port 0:  Range: 51.3 mm  Amplitude: 3728
```

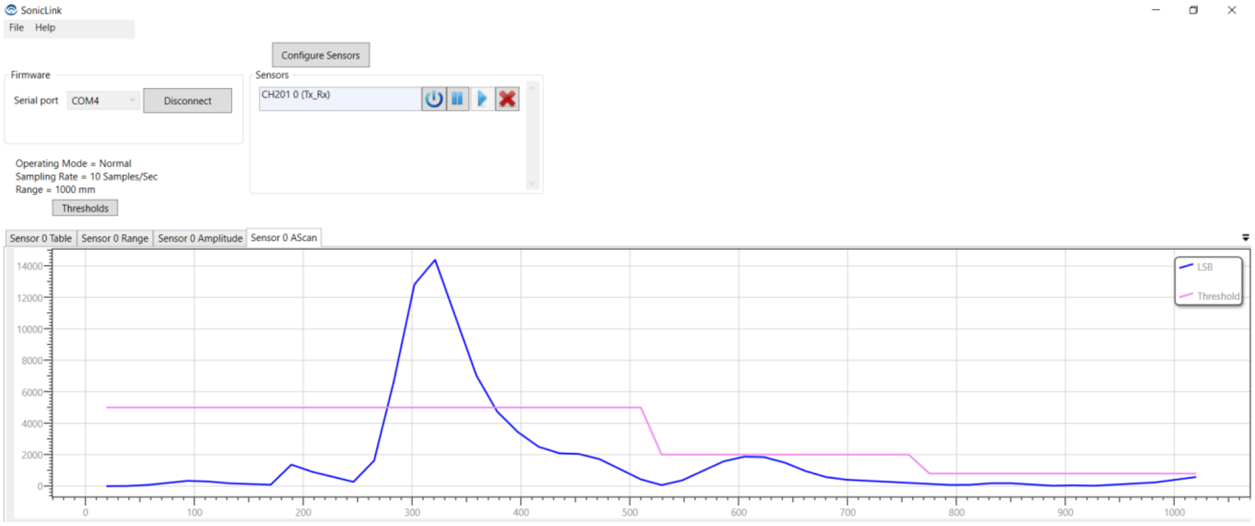
- Object is present with lower amplitude.

Figure 4-7. FinalTest Fail: Lower amplitude with object



- Baseline scan of sensor:

Figure 4-8. FinalTest Fail: Baseline scan



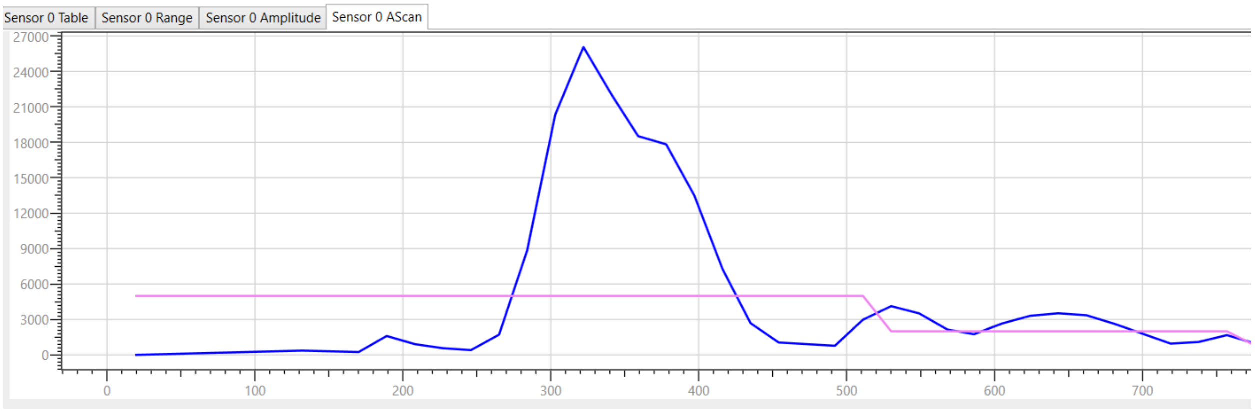
Serial port COM4

CH201 0 (Tx_Rx)

Operating Mode = Normal
Sampling Rate = 10 Samples/Sec
Range = 1000 mm

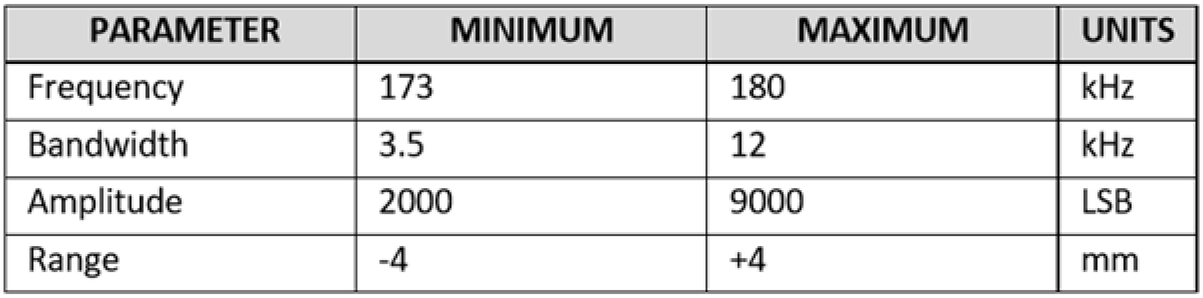
- This sensor failed bandwidth, reporting incorrect range.

Figure 4-9. FinalTest Fail: measure during ringdown



4.3 SAMPLE FINALTEST PARAMETERS

Figure 4-10. Example from MOD-CH101-03-01 module test



PARAMETER	MINIMUM	MAXIMUM	UNITS
Frequency	173	180	kHz
Bandwidth	3.5	12	kHz
Amplitude	2000	9000	LSB
Range	-4	+4	mm

5 ROBOTIC VACUUM CLEANER (RVC): FLOOR TYPE DETECTION

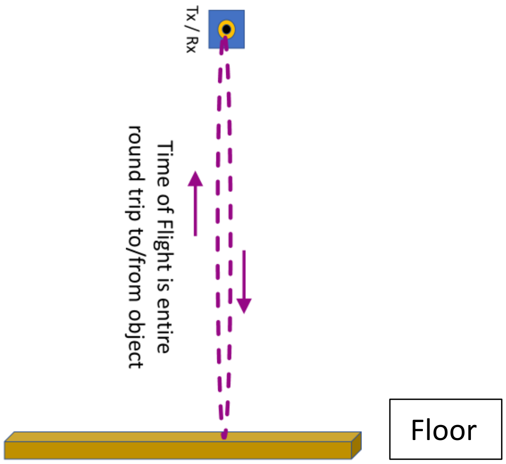
Using a CH101 sensor module, floor type detection can be performed to distinguish between a hard and soft floor surface such as a hardwood floor (hard) and carpet (soft). Real-time numerical data can be recorded and viewed in range vs. magnitude plots. With proper mounting, setup, and parameters, a custom apparatus can be controlled to determine floor types. Functions can be programmed into an MCU and used to control an RVC application.

Please refer to AN-000240 Application User Guide for Floor Type Detection of Robotic Vacuums

5.1 THEORY

To determine a floor type, a single pulse-echo CH101 sensor is used. These sensors measure the round-trip time that it takes for sound to be transmitted and returned to determine the distance. Figure 5-1 shows an example of the how the sensor detects a signal, in this case a floor surface. Using the data received, the floor type can be distinguished with various metrics. The floor type is determined by the strength of the return signal.

Figure 5-1. Floor Detection: Single-Sensor Pulse-echo



5.2 VALIDATION AND FLOOR TYPE DATASET

To build a dataset of floor types for preset (auto) parameters, both soft and hard floor types were used. Different carpet heights were used to have a wider range of data points. Figure 5-2 shows examples of the floor types that were used to build a soft and hard dataset.

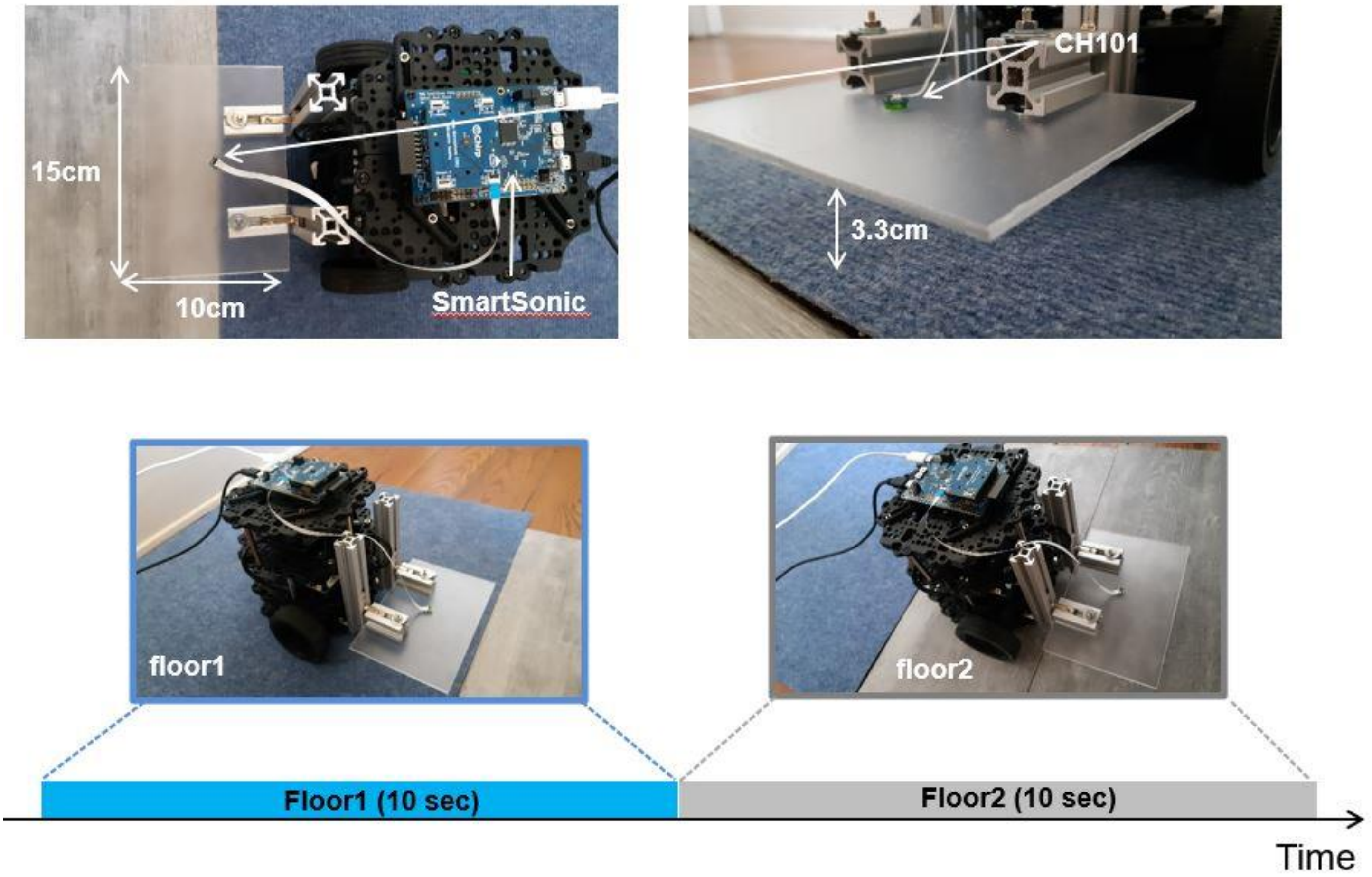
Figure 5-2. Floor types for Dataset

The validation experiment setup using a programed robot is shown in Figure 5-3. This setup met all the mounting requirements that have been stated in *Section* 3.3.3.

Experiment Steps:

1. Start (floor 1)
2. 10 sec back and forth (floor1)
3. Transition (floor 1 to floor 2)
4. 10 sec back and forth (floor 2)
5. End session (floor 2)

Figure 5-3. Floor Type validation setup



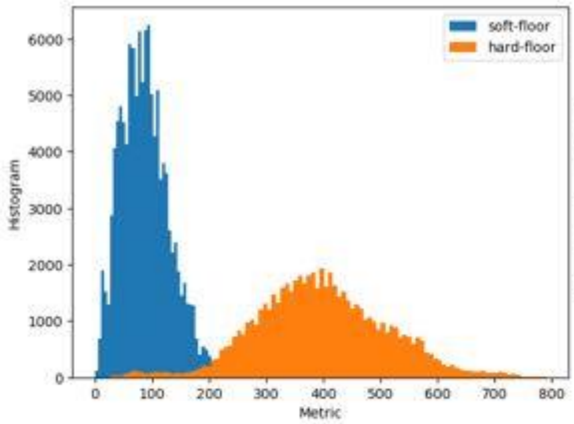
Using the setup above the following metric distribution can be seen in Figure 5-4 at the following heights. These histograms show the average detection of each soft and hard surface respectively at the state heights of the module from the floor. Using floor type datasets, thresholds can be setup for the surfaces that have been experimented on.

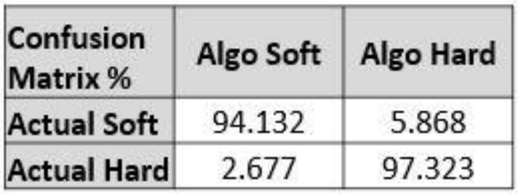
Figure 5-4. Floor Type Validation Detection Metric Distribution

Floor Height

Detection Rate

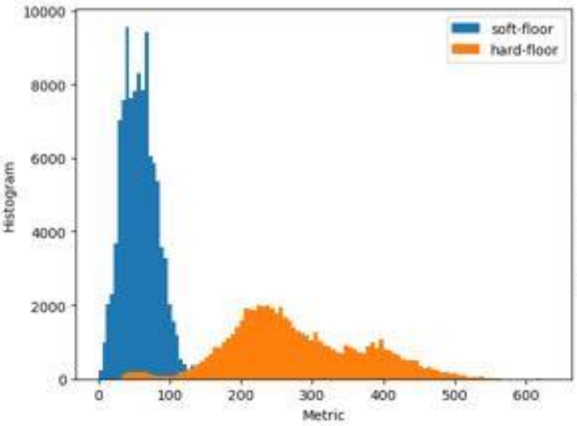
2.5 cm

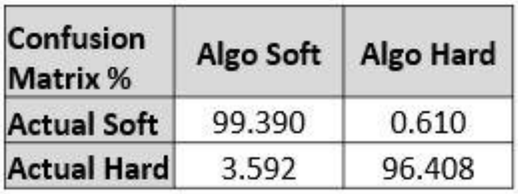




Confusion Matrix %	Algo Soft	Algo Hard
Actual Soft	94.132	5.868
Actual Hard	2.677	97.323

3.3 cm





Confusion Matrix %	Algo Soft	Algo Hard
Actual Soft	99.390	0.610
Actual Hard	3.592	96.408

5.3 ROBOFLOOR EXECUTABLE

To demonstrate the robotic vacuum cleaner floor type detection, the proper hardware and software need to be used. The ***RoboFloor_vX.X.X.exe*** has a compiled graphical user interface executable, hex files, and examples to output floor type detection with a CH101 module. The correct hardware mounting of the module will need to be performed and is explained in Section 3.3.3. These tools will allow the user to setup the module onto a desired product and the ability to program their MCU with an API library and tuned values.

5.4 HARDWARE PREPARATION

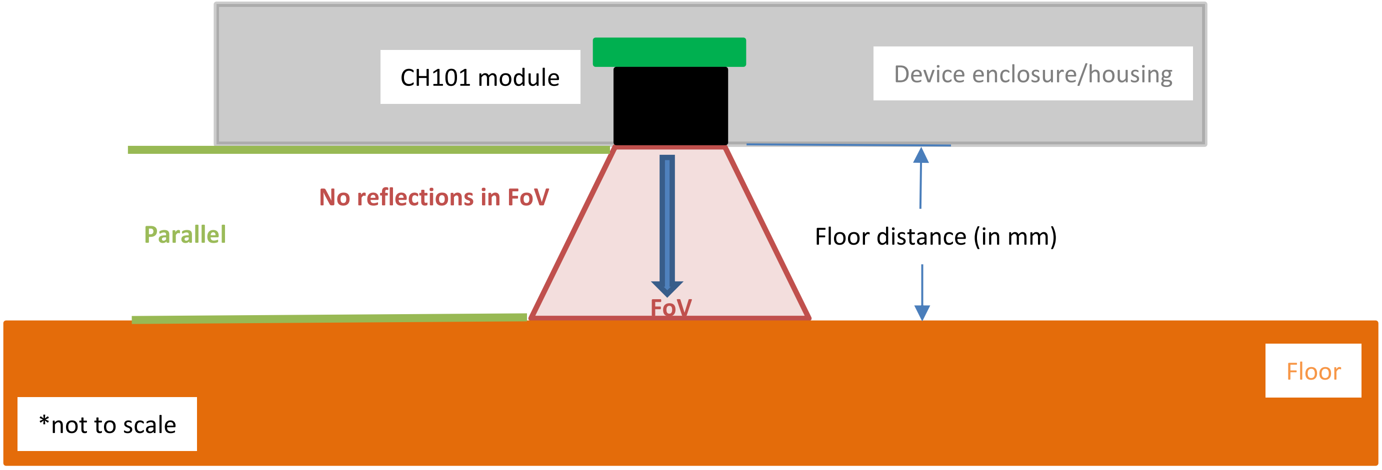
For the module to detect floor types, it must be mounted correctly. It is important to meet all mounting requirements and follow mounting suggestions. The mechanical integration guide, listed in Table 1-2, can be reviewed for a deeper dive into the module assembly and further explanation on the requirements listed below. Additional mounting requirements for CH101 modules can be seen in *Section 3.3.3*.

Mounting Requirements:

Mount the CH101 downward to a fixture, cart, or desired apparatus but ensure that it meets the list of requirements below.

- No reflecting objects in the FoV (below sensor and floor surface)
- Parallel to floor surface (no tilt angle)
- Set to desired distance
- Facing downward to the surface
- No residual force must be applied on the sensor and horn when mounting is complete

Figure 5-5. RVC mounting image



5.5 SETTINGS AND TUNING

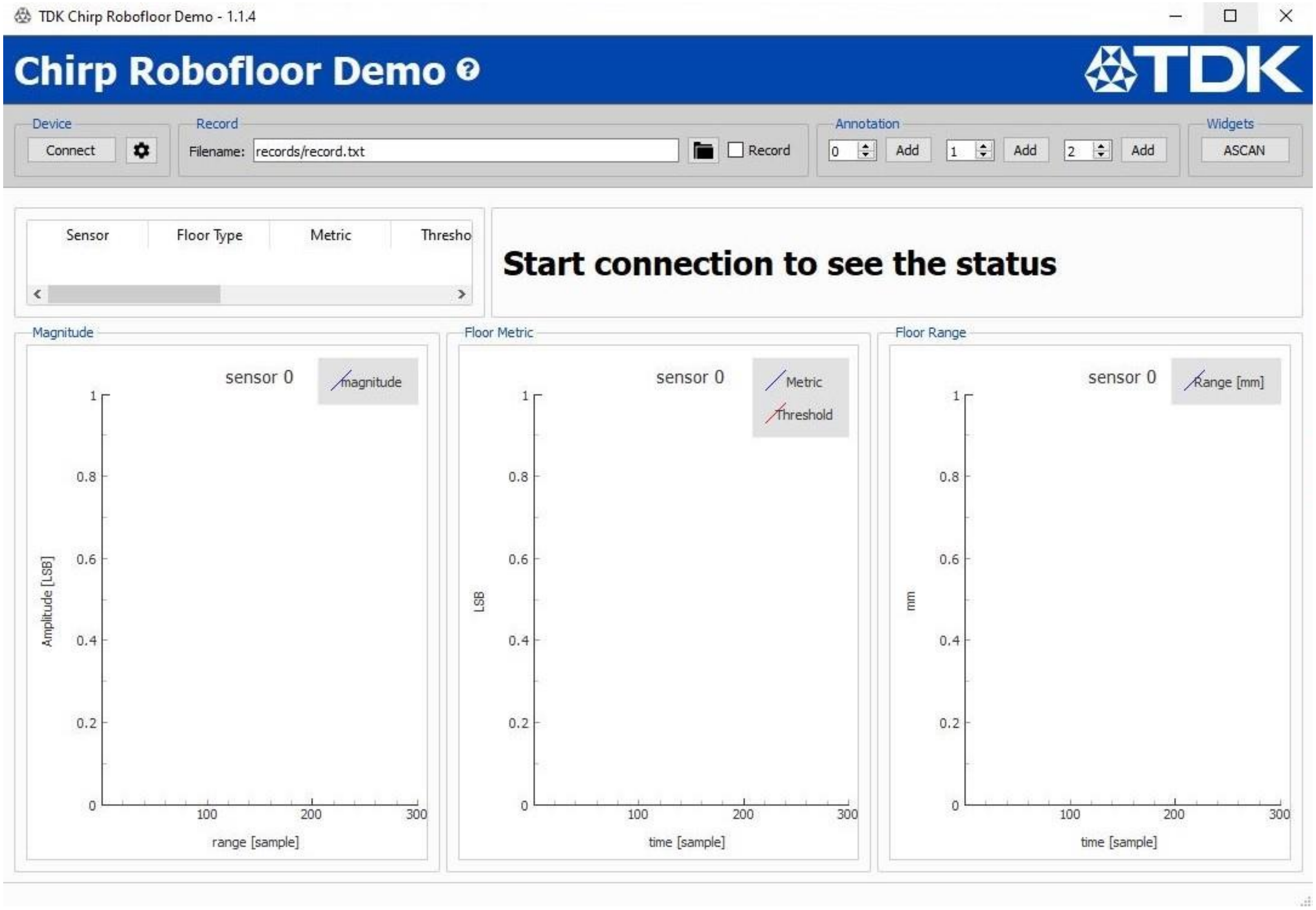
To understand the floor type parameters, a graphical user interface (GUI) is created to display real-time plots and output numerical values of its scans with automatic (auto) or custom (tuned) parameters. The auto parameters are based from validation data collected from different surface types and only the floor distance needs to be inputted to output floor metrics. For a more refined tuning parameters for custom setups, custom parameters are needed. These custom parameter values can be used to set the API functions and input into the MCU.

5.5.1 RVC Floor Type: Graphical User Interface (GUI)

A GUI allows the user to display real-time plots and output numerical values of its scans. The plots include range versus amplitude, time versus metric value (floor type threshold), and amplitude scan.

Figure 5-6 shows an example of the GUI displays. To run the GUI and floor type demonstration, refer to AN-000240.

Figure 5-6. RVC Floor Type GUI



TDK Chirp Robofloor Demo - 1.1.4

Chirp Robofloor Demo

Filename: records/record.txt

☐ Record

Start connection to see the status

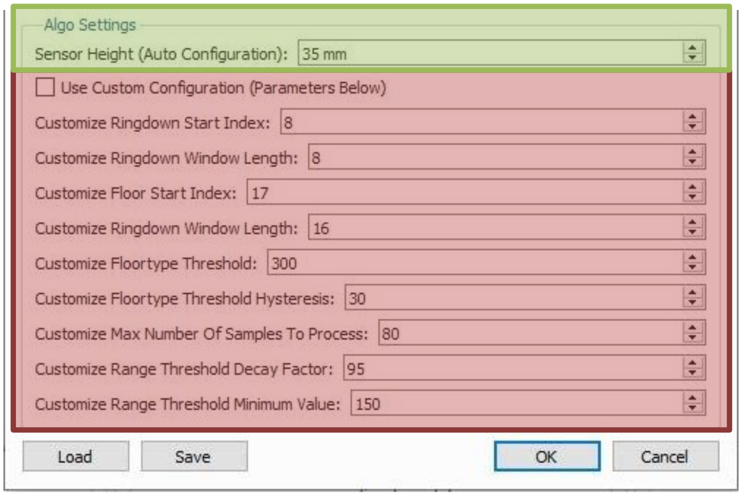
5.5.2 RVC Floor Type: Settings and Tuning

The GUI is used to display real-time plots and output numerical values of its scans with automatic (auto) or custom (tuned) parameters. The auto parameters are based from validation data collected from different surface types and only the floor distance needs to be inputted to output floor metrics. For a more refined tuning parameters for custom setups, custom parameters are needed. These customer parameter values, can be used to set the API functions and input into the MCU.

Auto Configuration

To use set parameters based from validation data collected from different surface types, only the floor height parameter needs to be set. All mounting requirements need to be met and the floor distance needs to be known. An example of an auto configuration using the GUI is shown below. The “Sensor Height” value in the settings needs to be set between 2.5-6cm (25-60mm). If a sensor height distance is input and the “Use Custom Configuration” is unchecked, all custom parameters are disregarded in red.

Figure 5-7. RVC Floor Type GUI: Auto configuration settings example

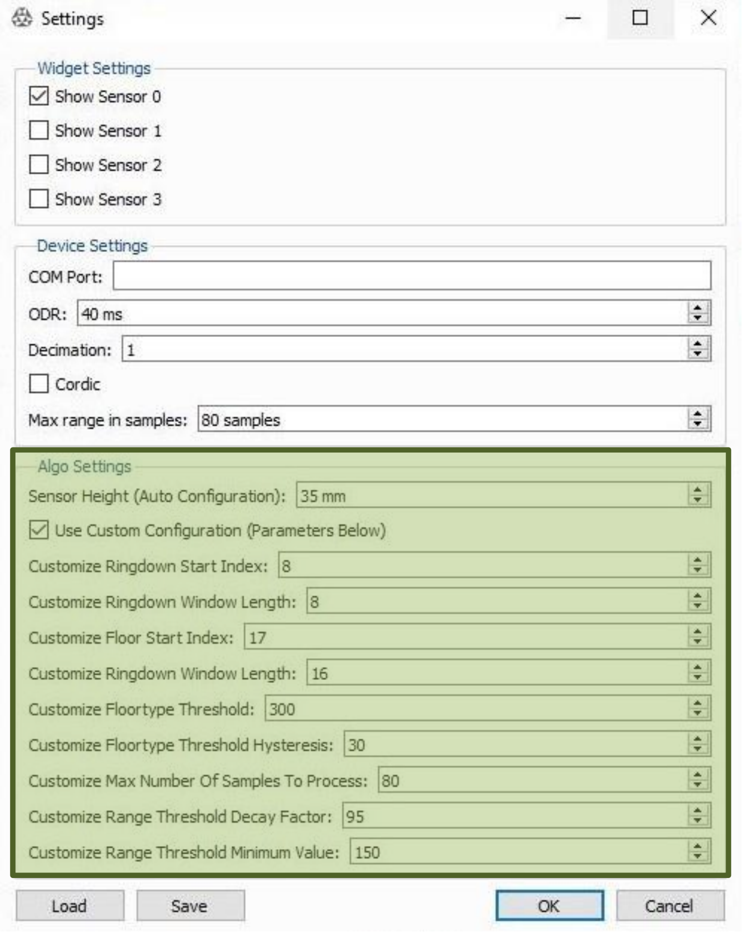


Algo Settings
Sensor Height (Auto Configuration): 35 mm
☐ Use Custom Configuration (Parameters Below)
Customize Ringdown Start Index: 8
Customize Ringdown Window Length: 8
Customize Floor Start Index: 17
Customize Ringdown Window Length: 16
Customize Floortype Threshold: 300
Customize Floortype Threshold Hysteresis: 30
Customize Max Number Of Samples To Process: 80
Customize Range Threshold Decay Factor: 95
Customize Range Threshold Minimum Value: 150

Custom parameters

For tuning to custom apparatus, floor types, or different setups, custom parameters will be needed to be used. This will help to refine the parameters to detect the floor surfaces to the setup. An example of a custom parameter configuration settings is shown in Figure 5-8.

Figure 5-8. RVC Floor Type GUI: Custom configuration settings example



Widget Settings
☑ Show Sensor 0
☐ Show Sensor 1
☐ Show Sensor 2
☐ Show Sensor 3

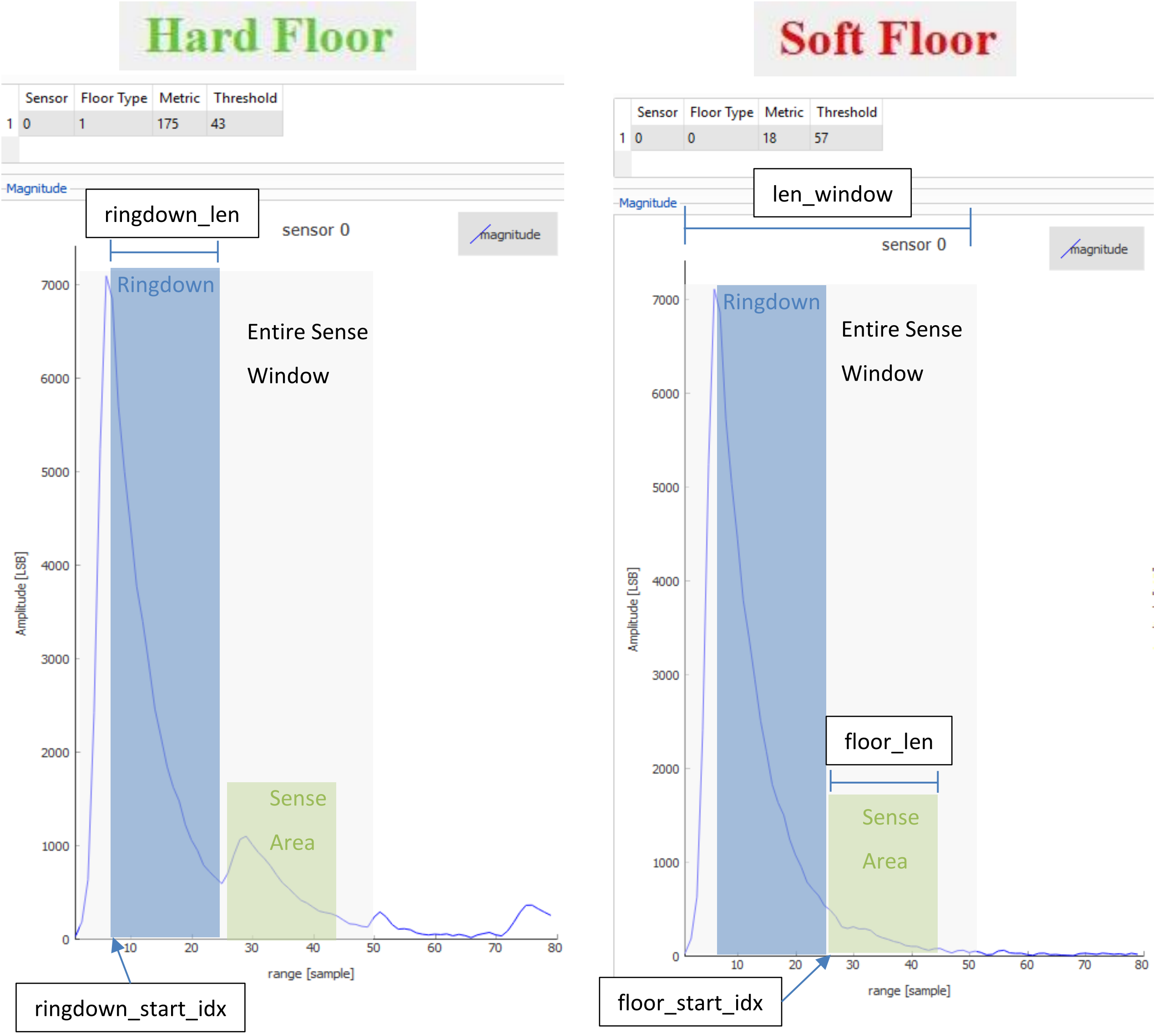
Device Settings
COM Port:
ODR: 40 ms
Decimation: 1
☐ Cordic
Max range in samples: 80 samples

Algo Settings
Sensor Height (Auto Configuration): 35 mm
☑ Use Custom Configuration (Parameters Below)
Customize Ringdown Start Index: 8
Customize Ringdown Window Length: 8
Customize Floor Start Index: 17
Customize Ringdown Window Length: 16
Customize Floortype Threshold: 300
Customize Floortype Threshold Hysteresis: 30
Customize Max Number Of Samples To Process: 80
Customize Range Threshold Decay Factor: 95
Customize Range Threshold Minimum Value: 150

Setting Descriptions:

- **Sensor height:** This parameter setup the library with recommended parameters given sensor height
    - Distance from the horn to floor surface. See *Section 5.4* mounting and *Section 5.5.2* for auto parameters
- **Use custom configuration:** Check this box to enable custom parameters below
- **Customize ringdown start index:** Define the index where ringdown started (typical is 8). Start index of window before floor reflection. Shift this setting to where ringdown begins or to desired starting point. After the peak of the amplitude.
- **Customize ringdown length:** Define the size of ringdown window (typical ringdown window ends before floor 1st echo)
- **Customize floor start index:** Define the index where floor echo started (depends on floor height). Occurs after ringdown section
- **Customize floor length:** Define the size of floor echo (typical size is 16 samples at decimation = 1)

Figure 5-9. RVC Floor Type GUI graphical plot labels



Hard Floor

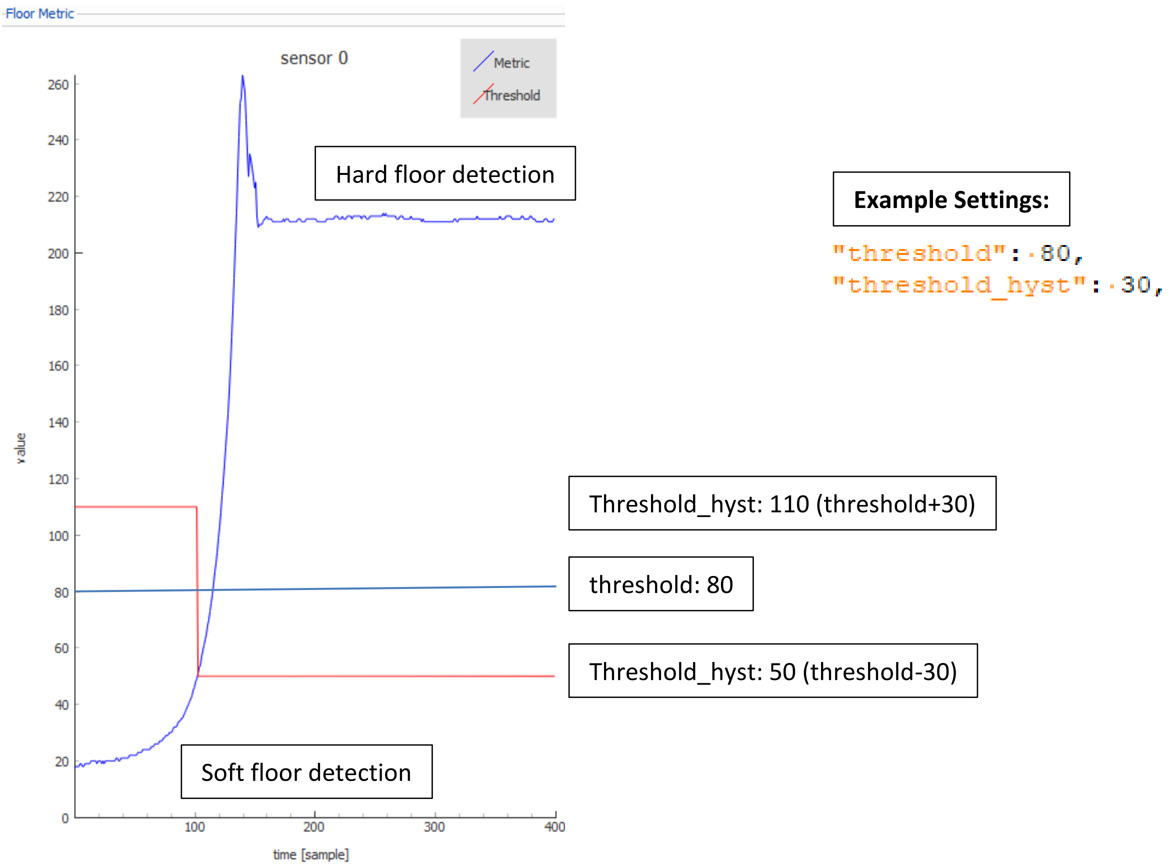
	Sensor	Floor Type	Metric	Threshold
1	0	1	175	43

Soft Floor

	Sensor	Floor Type	Metric	Threshold
1	0	0	18	57

- **Customize floortype threshold:** Threshold that classify floortype soft vs hard. The threshold should be reduced with higher sensor to floor distance
- **Customize floortype threshold hysteresis:** Threshold margin to avoid class toggling when metric transition
- **Customize max number of samples:** Set the max number of samples to process (typical value should cover the whole floor window)
- **Customize range threshold decay factor:** Decay factor of the threshold [0-100]. Impacts short distance detection: Low values improve detection sensitivity; Higher values reduce false positives.
- **Customize range threshold minimum value:** Lower bound of detection threshold. Impacts far distance detection.

Figure 5-10. RVC Floor Type GUI graphical plot threshold labels



Example Settings:

```
"threshold": 80,
"threshold_hyst": 30,
```

5.6 SONICLIB API

After getting a better understanding of how the parameters affect the metric output using the GUI and examples, Chirp SonicLib API functions can be used to program an existing MCU.

Please refer to AN-000175 SonicLib Programmers Guide for in depth explanation of using SonicLib API functions

Suggested steps are shown below:

1. Use exercise examples to familiarize with Chirp SonicLib sensor API.
    - Example: ‘invn.chirpmicro.smartsonic.robofloor-example.X.X.X.zip’
        - View *source/application/smartsonic-robofloor-example/src/main.c* file for extensive comments explaining how the SonicLib interfaces are used
    - Build application examples
2. Use RVC GUI to determine values.
    - Example: ‘Gui-demo-robofloor-x.x.x’
    - Refer to AN-000240: Application User Guide for Floor Type Detection of Robotic Vacuums
3. Review and determine the Chirp SonicLib sensor API functions needed along with the determined values of the functions from the GUI config settings.
    - See RVC Floor Type and RVC Cliff Detect sections
    - Refer to AN-000175-SonicLib-Programmers-Guide-v1.0
    - Refer to example App Notes for example specific available functions
        - Example: *source/application/smartsonic-robofloor-example/inc/app_config.h* file contains various settings that control the application’s behavior
4. Create config with the values.
    - Example: *floor_algo_config* to initialize algorithm
    - See *invn_algo_floor_type_fxp.h* file for more information on each parameter.
5. This can be used to program into the MCU

6 ROBOTIC VACUUM CLEANER (RVC): FLOOR TYPE AND CLIFF DETECTION

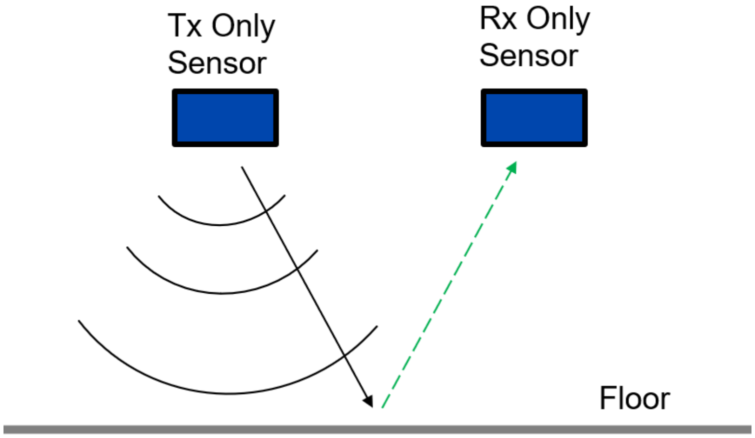
Using a two CH101 sensors, floor type and cliff detection can be performed. Floor type detection is the differentiation between hard floors (hardwood, tile, etc) and soft floors (carpets). Cliff detection is the detection of a cliff, such as an overhanging ledge, stairs, or other similar risk to an RVC.

Please refer to AN-000349 Application User Guide for Floor Type Detection of Robotic Vacuums

6.1 THEORY

The CH101 is an ultrasonic ToF transceiver that measures the distance of an object based on how long it takes for ultrasound transmitted from the sensor to be reflected back and received by the sensor. There is a certain amount of time after transmission for the sensor to stop vibrating (ringdown) from the transmit pulse before it can accurately receive the reflected ToF signal. To get around the ringdown issue while operating only a few centimeters from the floor, a second sensor is used as a dedicated receiver and the two sensors operate in Pitch-Catch mode. In this mode, the receiving sensor does not have to deal with the ringdown issue and it's time constraints.

Figure 6-1. Operating principle of the two-sensors in Pitch-Catch for this cliff and floor type detection application

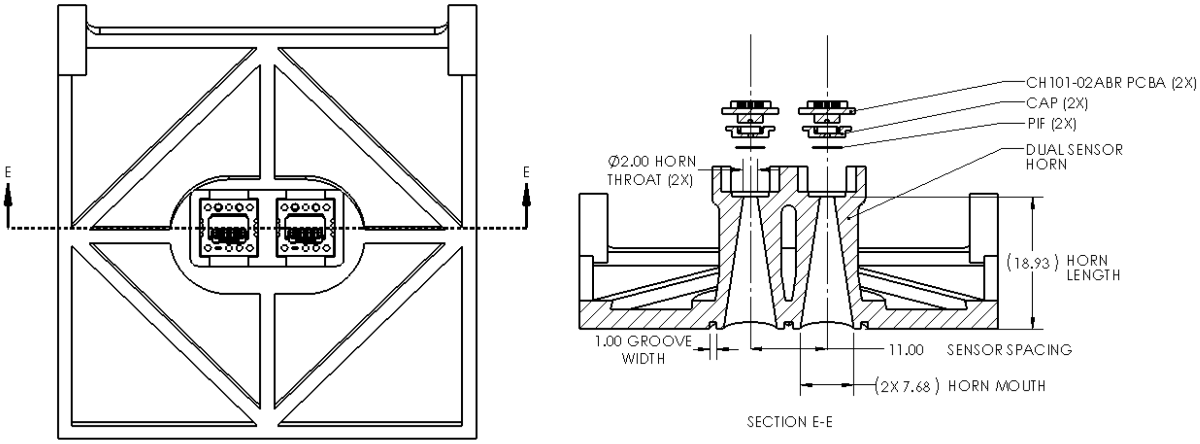


Different surfaces (floor types) will produce different amplitude reflections, with soft floors reflecting less and producing a lower amplitude echo, while hard surfaces will produce a higher amplitude echo. The ToF of this echo also indicates how far away the sensor is from the floor. When the ultrasound echo's ToF is longer than a specified time duration, it means that there is a large gap between the sensor and the floor, thus indicating there is a cliff in front of the sensor.

6.2 ACOUSTIC INTERFACE

The two-sensor cliff detection reference design utilizes a carefully designed Acoustic Interface to achieve optimal performance. A picture of the reference design Acoustic Interface is shown below.

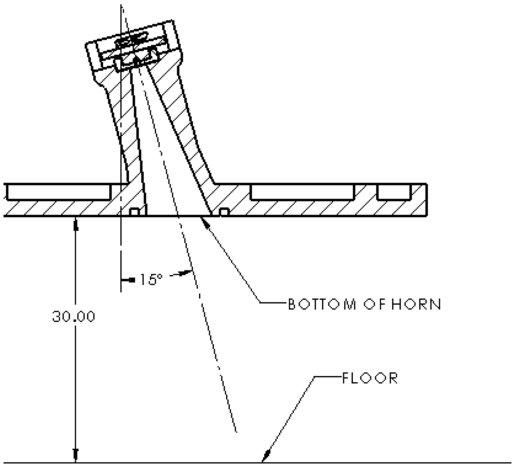
Figure 6-2. Cross-section view of the 2-sensor cliff detect Acoustic Interface reference design



6.3 MECHANICAL AND MODULE SETUP

The floor type and cliff detection algorithm are tuned and expect the sensor to be placed and orientated in a specific position for optimal performance. The recommended design places the bottom on the Acoustic Interface 30mm from the floor. The bottom surface of the RVC containing the Acoustic Interface should be parallel to the floor and the angle of the axis of the horn should be tilted 15 degrees from vertical. The forward tilt of the horn allows the sensor to “look” ahead and detect cliffs earlier. However, too much tilt will result in less of the reflected signal from the floor being returned to the sensor, reducing algorithm accuracy.

Figure 6-3. Cross-section of one of the sensor modules



6.4 SETTINGS AND TUNING

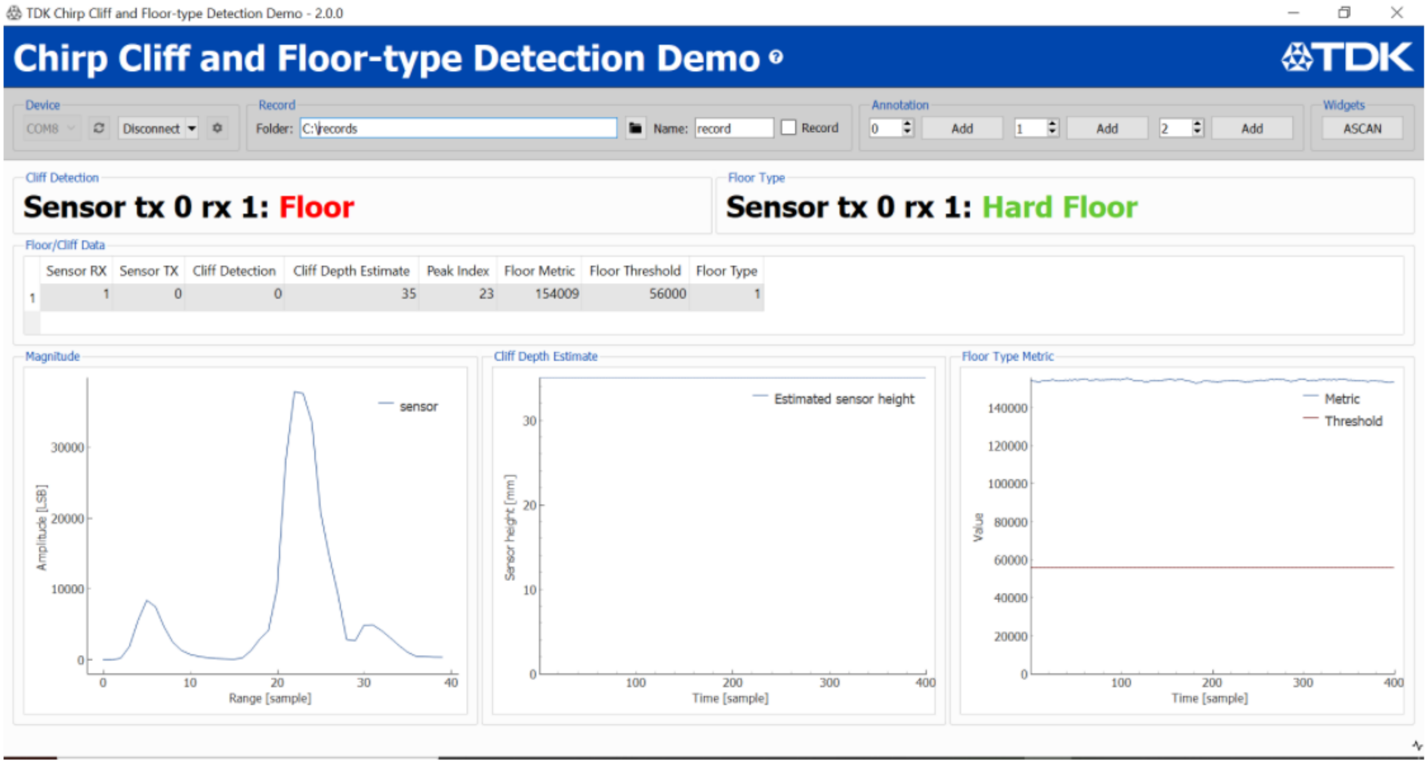
To understand the floor type and cliff parameters, a graphical user interface (GUI) is created to display real-time plots and output numerical values of its scans. For a more refined tuning parameters for custom setups, custom parameters are needed. These custom parameter values can be used to set the API functions and input into the MCU.

6.4.1 RVC Cliff & Floor: Graphical User Interface (GUI)

A GUI allows the user to display real-time plots and output numerical values of its scans. The plots include range versus amplitude, time versus metric value (floor type threshold), Cliff Depth Estimate and amplitude scan.

Figure 5-6 shows an example of the GUI displays. To run the GUI and floor type demonstration, refer to AN-000349.

Figure 6-4. RVC Cliff and Floor Type GUI



Folder: C:\records

Name: record

☐ Record

Annotation: 0, 1, 2

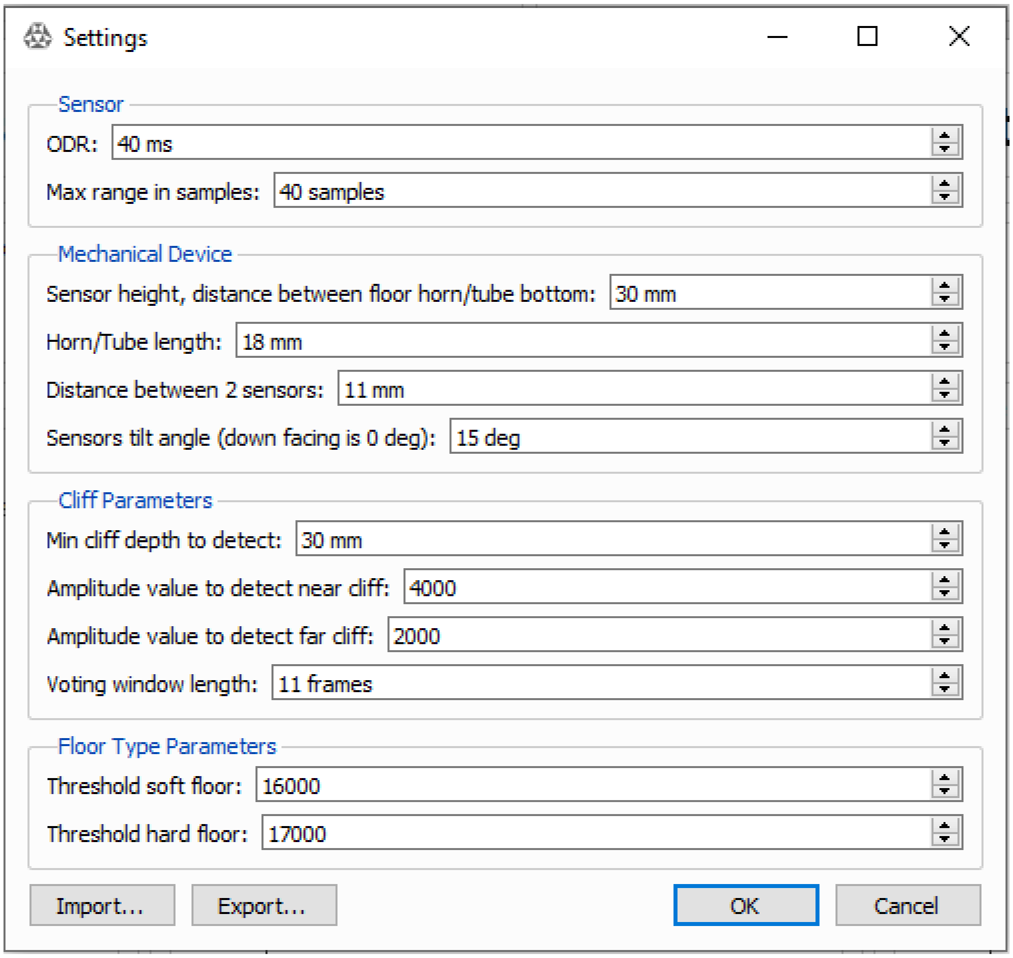
Sensor tx 0 rx 1: Floor

Sensor tx 0 rx 1: Hard Floor

	Sensor RX	Sensor TX	Cliff Detection	Cliff Depth Estimate	Peak Index	Floor Metric	Floor Threshold	Floor Type
1	1	0	0	35	23	154009	56000	1

6.4.2 RVC Cliff & Floor: Settings and Tuning

Figure 6-5. RVC Cliff and Floor Type GUI settings



Settings

Sensor

ODR: 40 ms

Max range in samples: 40 samples

Mechanical Device

Sensor height, distance between floor horn/tube bottom: 30 mm

Horn/Tube length: 18 mm

Distance between 2 sensors: 11 mm

Sensors tilt angle (down facing is 0 deg): 15 deg

Cliff Parameters

Min cliff depth to detect: 30 mm

Amplitude value to detect near cliff: 4000

Amplitude value to detect far cliff: 2000

Voting window length: 11 frames

Floor Type Parameters

Threshold soft floor: 16000

Threshold hard floor: 17000

Sensor settings:

- **ODR:** The time interval at which the sensor should be periodically triggered to take a measurement. Reducing ODR increases the data bandwidth required to transfer data from the sensor to the host. A 40ms ODR is equal to a data acquisition frequency of 25Hz. Default value is 40ms. Range of permitted values is [10, 1000].
- **Max range in samples**: The number of IQ traces to acquire for each sensor measurement. Higher values allow the sensor to search for echoes further away, but also increases the amount of data collected, the data transfer time, and data processing time. The cliff detection algorithm has the best performance at 40 samples. Default value is 40 samples. Range of permitted values is [20, 80].

Mechanical Device settings:

- **Sensor height**: Distance between the floor and the bottom of the horn (e.g. bottom of the robot) in mm. Default value is 30mm. Range of permitted values is [0, 140].
- **Horn/Tube length**: Length of horn/tube in mm. Default value is 18mm. Range of permitted values is [2, 50].
- **Distance between 2 sensors**: Center-to-center distance between the two sensors (how far they are spaced apart from each other). Default value is 11mm. Range of permitted values is [10, 60].
- **Sensor tilt angle**: Sensor tilt angle relative to the floor, in degrees. Sensor pointing directly down at the floor is 0 degrees. Default value is 15 degrees. Range of permitted values is [0, 45].
- For best algorithm performance, all physical input measurements should be accurate to +/- 1 mm or +/- 1 degree.

Cliff Parameters settings:

- **Min cliff depth to detect**: The minimum cliff depth that should be detected and considered as a cliff. Cliff depths that are smaller than this value will be treated as a regular floor. Default value is 30mm. Range of permitted values is [10, 140].
- **Amplitude value to detect near cliff**: The amplitude threshold to consider an ultrasound echo as a short-range cliff. Default value is 4000 LSBs.
- **Amplitude value to detect far cliff**: The amplitude threshold to consider an ultrasound echo as a long-range cliff. Default value is 2000 LSBs.
- **Voting window length**: Length of detection voting window in number of frames. This parameter is used to smooth the instantaneous detection result. Lower values will result in faster algorithm reaction, but also will increase likelihood of false cliff detections. Set this parameter to balance between reaction time and false detection frequency. Default value is 11 frames. Range of permitted values is [1, 101].

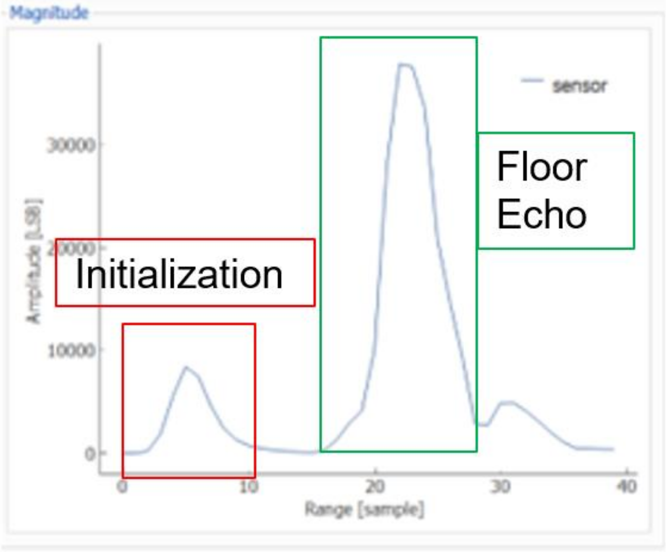
Floor Type Parameters settings:

- **Threshold soft floor**: Initial threshold on the floor type detection metric. Values below this threshold will be considered a soft floor.
- **Threshold hard floor**: Initial threshold on the floor type detection metric. Values above this threshold will be considered a hard floor.

6.5 GUI OUTPUTS

The “Magnitude” plot displays the return echo signal as measured by the receive-only sensor. The first peak is the initialize phase of the receive sensor, which results from powering up and waking the sensor. The second peak is the actual echo from the floor, that was originally sent from the transmitter sensor. The relative magnitude of this peak determines whether the algorithm will classify the floor as a soft floor (low amplitude) or hard floor (high amplitude).

Figure 6-6. Example RVC Cliff and Floor Type GUI display output



The “Floor Type Metric” plot displays the algorithm’s calculated metric for the amplitude of the floor’s return echo over time. If the RVC is transitioning between hard and soft floors, the metric’s displayed value will correspondingly change along such floor transitions. While the RVC is moving, there will be some fluctuations in the floor type metric and its normal sensor behavior.

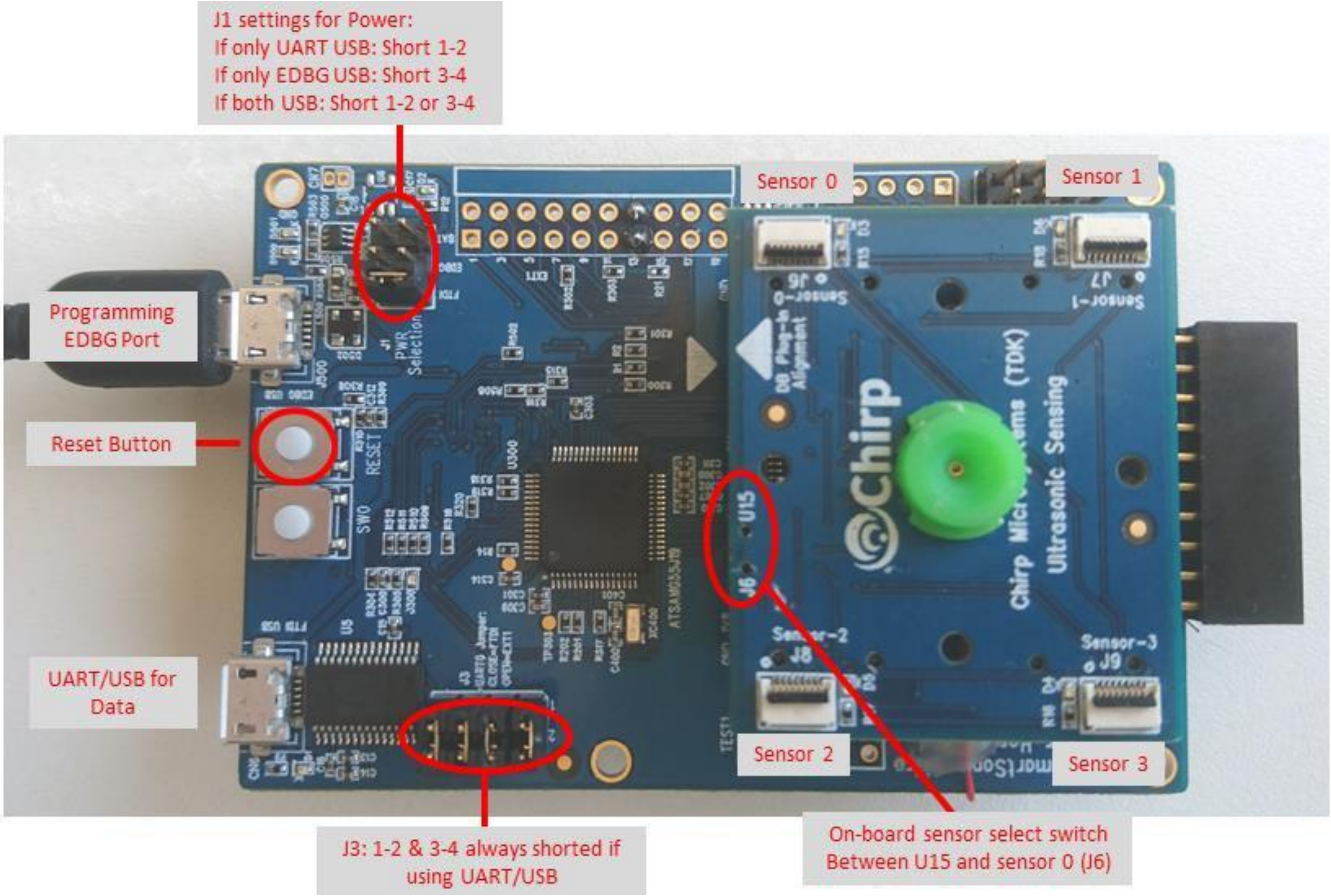
The “Cliff Depth Estimate” plots the cliff detect algorithm’s estimate for the cliff depth/size over time. In the Magnitude plot, the floor echo’s position will determine if the algorithm classifies the situation as a floor or cliff. If the echo is too far away, or no echo is detected, the algorithm will consider it a cliff situation. If the sensor or RVC is moved up and down relative to the floor, this plot will correspondingly track the sensor/RVC’s vertical motion.

7 APPENDIX

7.1 SMARTSONIC AND DAUGHTERBOARD HARDWARE

The DK-x01 SmartSonic hardware out-of-box is shown below. Note that the horn on the daughter board may differ from the picture. Refer to the reference documentation for more information.

Figure 7-1. SmartSonic Hardware basics



8 REVISION HISTORY

Revision Date	Revision	Description
02/19/2021	1.0	Initial Release
09/10/2021	1.1	Updated schematic and source code sample in Section 2.4.1
03/25/2022	1.2	Updated Section 2.4: Using Level Shifters and Section 5: RVC Floor Type; Added Section 6: RVC Floor/Cliff Section. Minor corrections

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